Proceedings of the ICE JAM SEMINAR

June 2, 1982

Queen's Park, Toronto

Ontario
Ministry of Natural Resources
Hon. Alan W. Pope
Minister
John R. Sloan
Deputy Minister

FOREWORD

The seminar was a follow up to the Ice Management Seminar sponsored by the Ministry of Natural Resources, Southwestern Region, held on January 30, 1980 in London, Ontario. It was organized by the staff of the Conservation Authorities and Water Management Branch as part of its Ice Jam Study Program, and was held in conjunction with the Canada-wide lecture tour of Dr. E. Tsykin, formerly head of the Ice Engineering Laboratory of the USSR Academy of Sciences.

The proceedings include, in their entirety, the papers prepared or presented by the authors. In the case of Dr. Tsykin, we have prepared the two texts for inclusion in the Proceedings from notes supplemented by handouts distributed by Dr. Tsykin at the Seminar. Because of the logistic problems, we have not had the benefit of his review on the texts. We are solely responsible for any errors or misinterpretations in these texts.

We were grateful to Mrs. Heda Whitson who helped organize the Seminar, prepared a record of discussions and produced a camera-ready copy of these Proceedings.

Since the holding of the Seminar, the Ice Management Manual, as discussed by Mr. Garrett in his welcoming address, has been published. A complimentary copy is available by writing to the Director, Conservation Authorities and Water Management Branch.

December, 1983

John Ding

Derek Foulds

Co-editors

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MINISTRY OF NATURAL RESOURCES

CONSERVATION AUTHORITIES AND WATER MANAGEMENT BRANCH

ICE JAM SEMINAR

June 2, 1982

Temagami Room, Macdonald Block

Queen's Park
Toronto, Ontario

AGENDA

9:30	Coffee and Donuts	
9:45	Welcome	M. R. Garrett
10:00	Overview of Ice Problems in Ontario	D. Foulds
10:30	Ice Jams: Origin and Determination of Control Measures	E. Tsykin
12:00	Lunch	
1:00	Case Study: Monitoring Ice Jams on the Grand River	P. Frigon
1:30	Principles of Ice Jam Prevention: Ontario Experiences	D. Foulds
2:30	Coffee	
3:00	Methods of Ice Jam Control: Solar Ice Melting, Mechanical Ice Destruction and Use of Ice Breakers	E. Tsykin
4:00	Discussion	E. Tsykin D. Foulds P. Frigon
4:30	Adjourn	

WELCOME ADDRESS

by M. R. Garrett, Director

Conservation Authorities and Water Management Branch

Ministry of Natural Resources

Ladies and Gentlemen:

On behalf of the Ministry of Natural Resources, I would like to welcome you to this Ice Jam Seminar sponsored by the Conservation Authorities and Water Management Branch.

For those of our guests who may not be familiar with the Branch, we provide policy direction and technical and financial assistance through MNR's Regional Offices to Ontario's 39 Conservation Authorities in the water and related land management program. We also provide technical assistance to our own Regional Offices in the water management field.

Ice jam flooding is a chronic problem in Ontario, as exemplified by the recent events such as those that occurred in March 1979 in Dover Township, March 1980 in Port Hope, and the widespread floods in February 1981 and in Crysler in 1982.

Derek Foulds and some climatologists have been trying to tell us that we are entering into a mini ice age. This will mean that ice jams will likely become more and more serious in the 1980s.

Acting on numerous requests from MNR's Regional Offices and Conservation Authorities for guidance and procedures for dealing with ice jams, the Conservation Authorities and Water Management Branch initiated an ice jam study program in 1980. The prime objective of the program was to prepare a manual that would include guidelines and procedures for monitoring, predicting and acting on ice break-up and jamming on rivers in Ontario where the history of ice jams is frequent and well known.

As part of the program, the Branch initiated co-operative projects with the Grand River, Ganaraska Region and Credit Valley Conservation Authorities for the purposes of identifying factors affecting ice jams and collecting other pertinent data such as ice cover, air temperature and streamflow data. In addition, special investigations on specific ice jam problem areas in

northern Ontario such as the Goulais River near Sault Ste. Marie, and Town Creek in Timmins were carried out. It was intended that data and information obtained from these activities would be helpful in the preparation of the manual.

Another important component of the program was to review and document the history of ice jam problems and remedial measures in the province. This included the documentation of the causes and extent of the events in February 1981, which covered the southern half of the province.

The draft manual is now available for comment and feedback. It is the product of all activities and studies that have been undertaken under this program since 1980. It is hoped that the information provided will be useful in preventing and dealing with the many ice jam related problems that are encountered in the province.

Our guest speaker, Dr. Tsykin, before emigrating to Australia, was for 20 years in charge of the Ice Engineering Laboratory of the USSR Academy of Sciences in Moscow, and did original work on ice jams, ice destruction techniques and other ice-related problems.

From the perspective of Ontario, Derek Foulds, a consultant to the Branch, and Paul Frigon, of the Grand River Conservation Authority, will present some of the work they have been conducting in the preparation of the Ice Management Manual. I believe all of us will learn from their experiences of such an important subject which is unique to the cold climate in which we live.

I encourage all of you to actively participate in the Seminar and discuss any ice jam problems you have in your Authority or Region. I would also ask you to help us identify problem areas for further study. The Ice Management Manual we are distributing at this Seminar has already gone through two drafts and, with your help, I hope we can put out a final draft, if not the final report, in time for the next ice jam season.

I also look forward to your feedback on this seminar. We will be striving to improve the Branch's response to your applied research needs, and any suggestions you have in this regard will be welcomed.

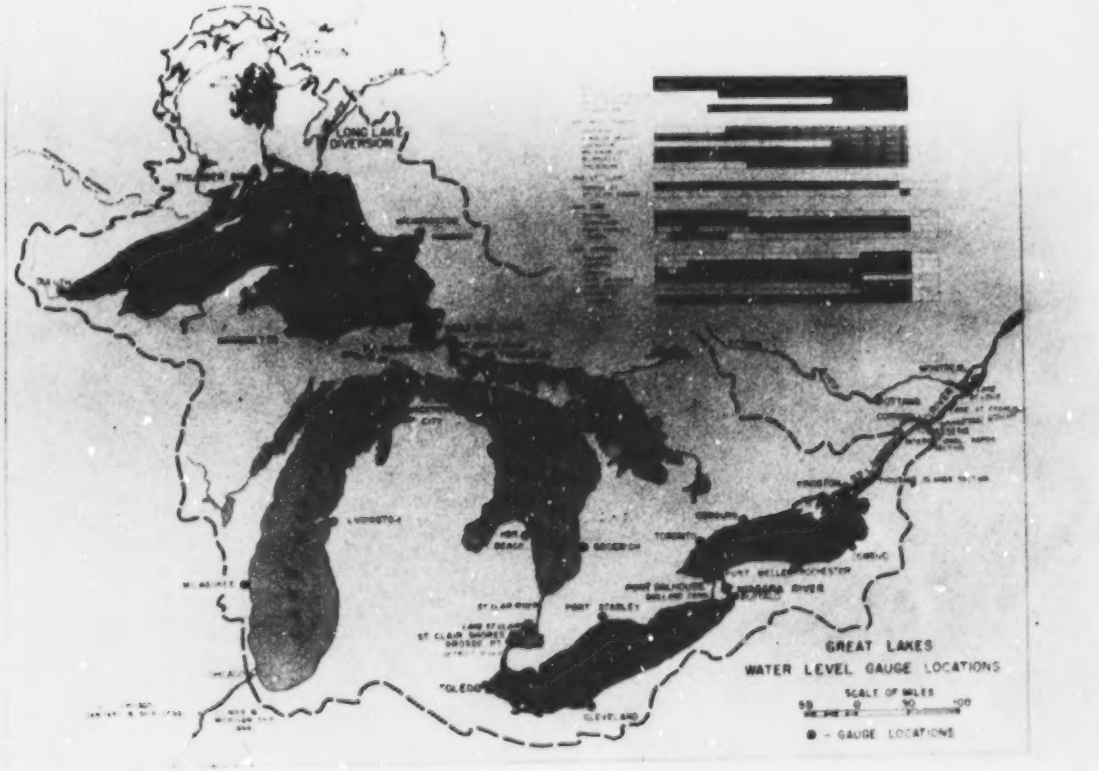
ICE PROBLEMS IN ONTARIO

by

D. M. Foulds

Uxbridge, Ontario

This talk was heavily dependent on slides and this description, therefore, will tend to be on the inadequate side.

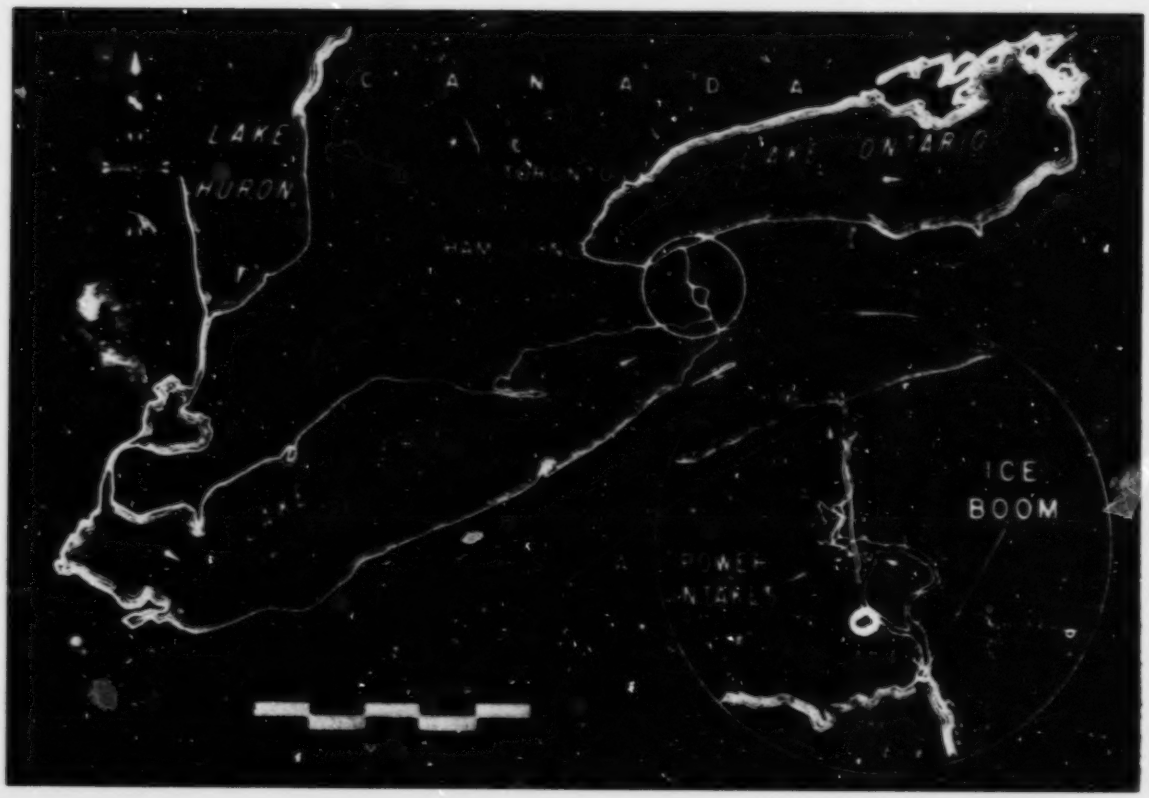


Slide 1 — You will all recognize this slide as one showing the Great Lakes and their drainage area. It contains all the rivers and ice problems I will be talking about, and not all the ice probiems occur in the northward flowing streams. Mike Garrett has mentioned that the northern flowing streams have special problems and this is true. However, I'm here to tell you that the southern flowing ones do, too.

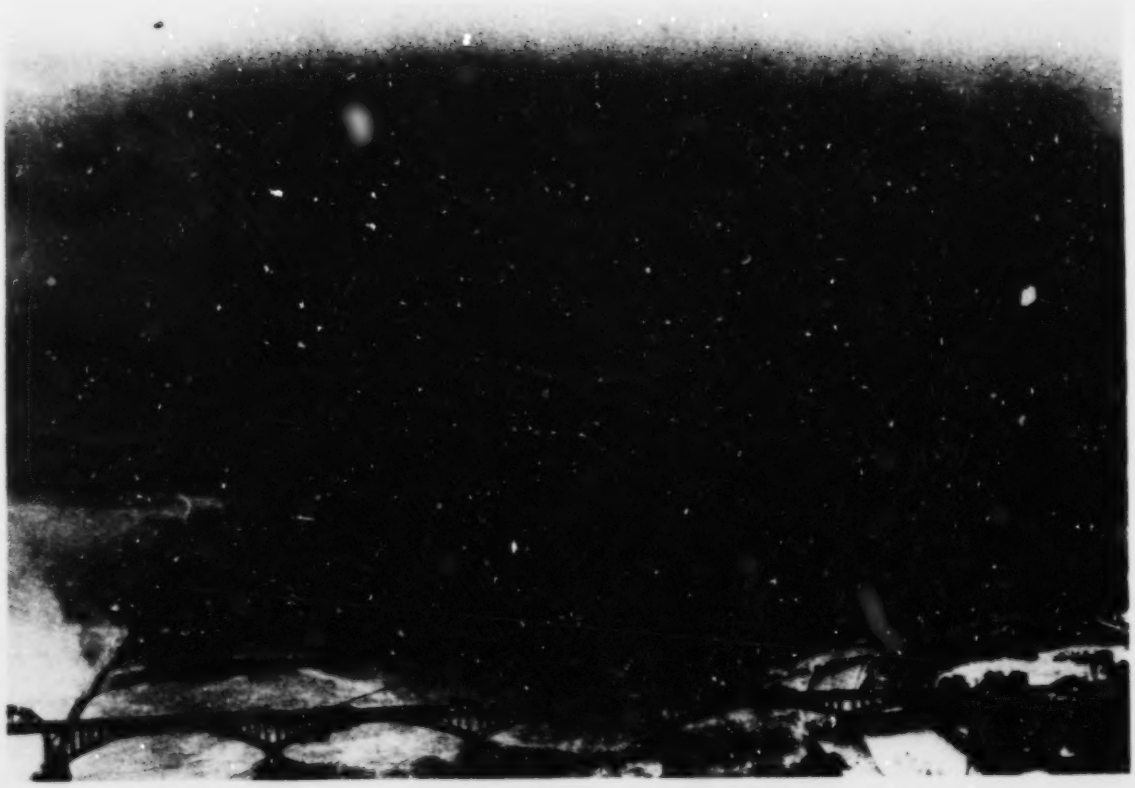
Most of our chronic problems occur south of a line running between Wiarton on the Bruce Peninsula and Cornwall, and this is roughly latitude 44°. North of that line, the climate tends to be less variable and colder, and there are less frequent problems.

The same line very roughly corresponds with what Peter Gryniewski calls the "snow line", and it is the rivers which have their headwaters on one side of the line and their outlets on the other side which give the greatest problems.

I'm going to use some slides which illustrate typical problems. On a large scale, they are indicative of what can happen on your watershed, and they have the advantage of being available. It is extremely difficult to get such pictures, as the problems often take place at night, on week-ends, etc.



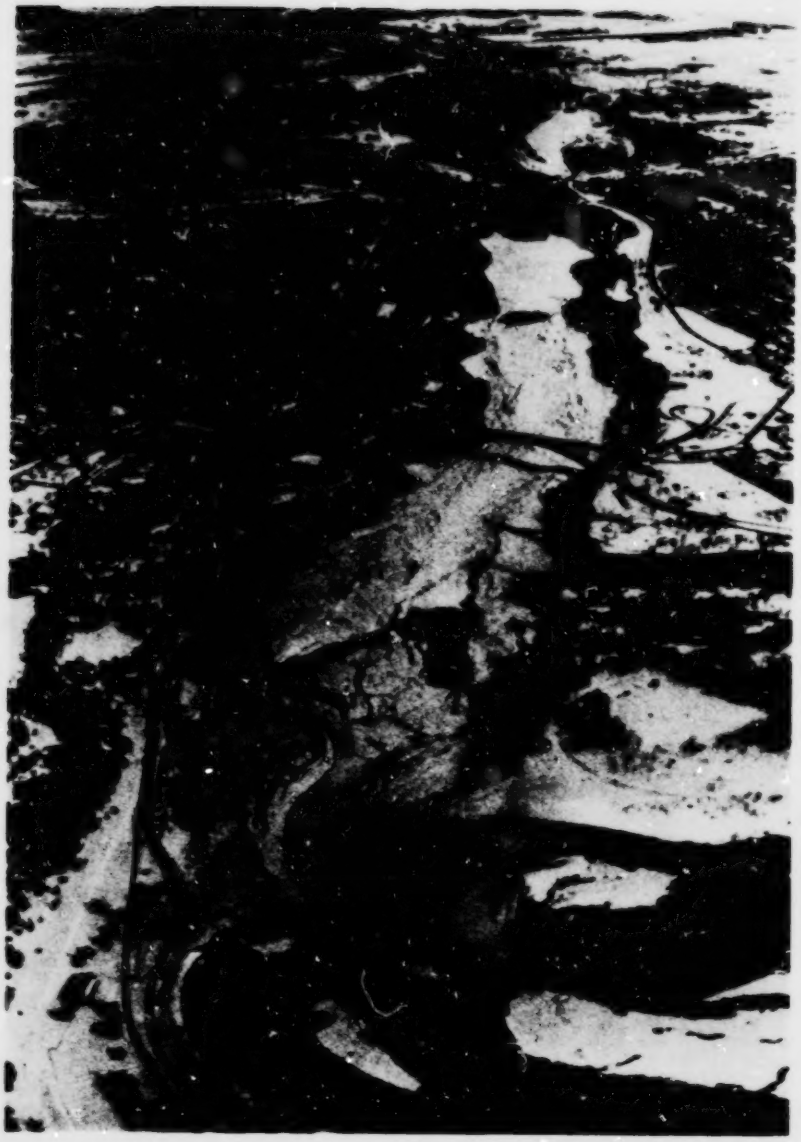
Slide 2 The Niagara River from Lake Erie to the falls to Lake Ontario.



Slide 3 The Peace Bridge between Buffalo and Fort Erie, with a single ice pan being compressed by the shores and broken by the piers. Note the wall in the right-hand edge where the ice is trying to climb over.

Slide 4 Close-up of ice climbing the wall.

Slide 5 A little later, after the ice has passed.



Slide 6 So what's the problem?

A picture of the Maid of the Mist pool looking downstream over the Canadian or Horseshoe Falls. Ice in the gorge is jammed for 3 km, and the Ontario Generating Station in the lower left-hand corner is under pressure.

Slide 7

The Ontario Power House Generating Station after the ice pressure had broken the windows in 1909. After the first winter's experience, they bricked in the lower half of the windows, and nothing serious happened again until 1938 when the ice came in the upper half of the windows, and also demolished the Honeymoon Bridge. Again the windows were bricked in - to the top this time - and the plant continued to operate until the winter of 1964.

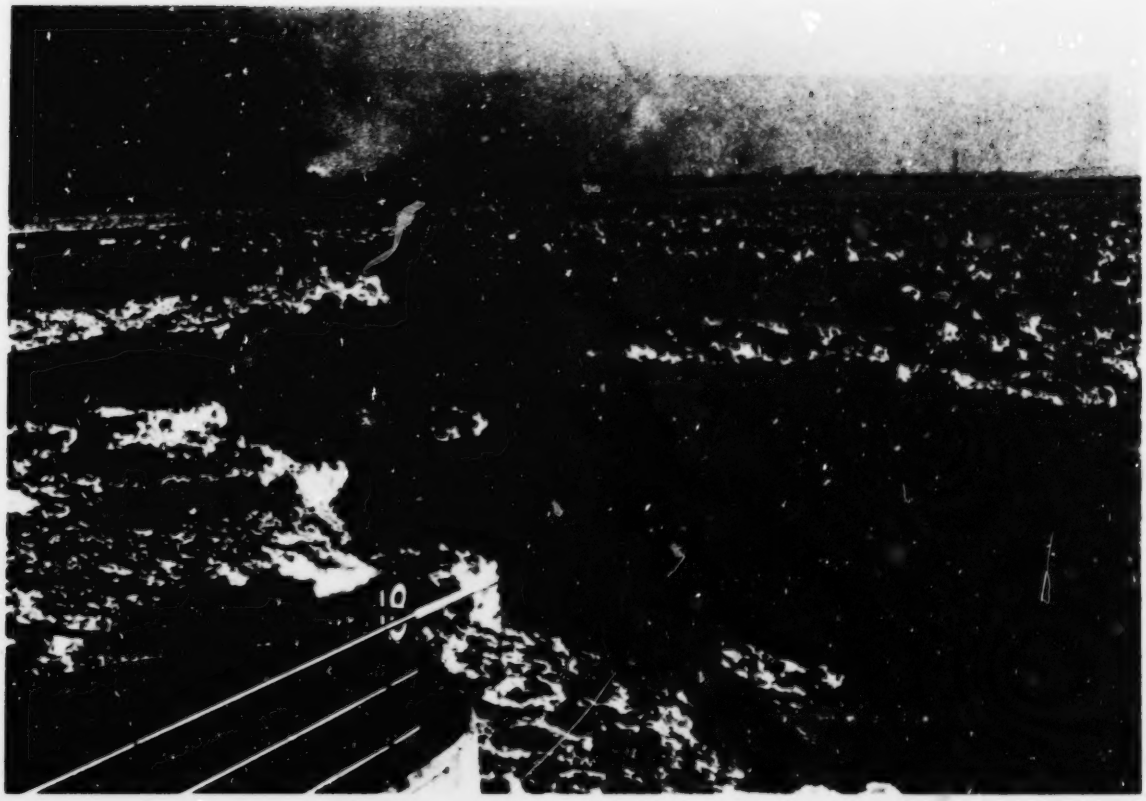
Slide 8 (1964) A major January storm caused this kind of pile-up in Lake Erie. Ice 10 m high in water 8 m deep and over 2 km from shore.

Slide 9 Ice water mark on trees, showing where the seiche drove the water level (and ice), and also some of the stranded pieces which are over 1 m thick.

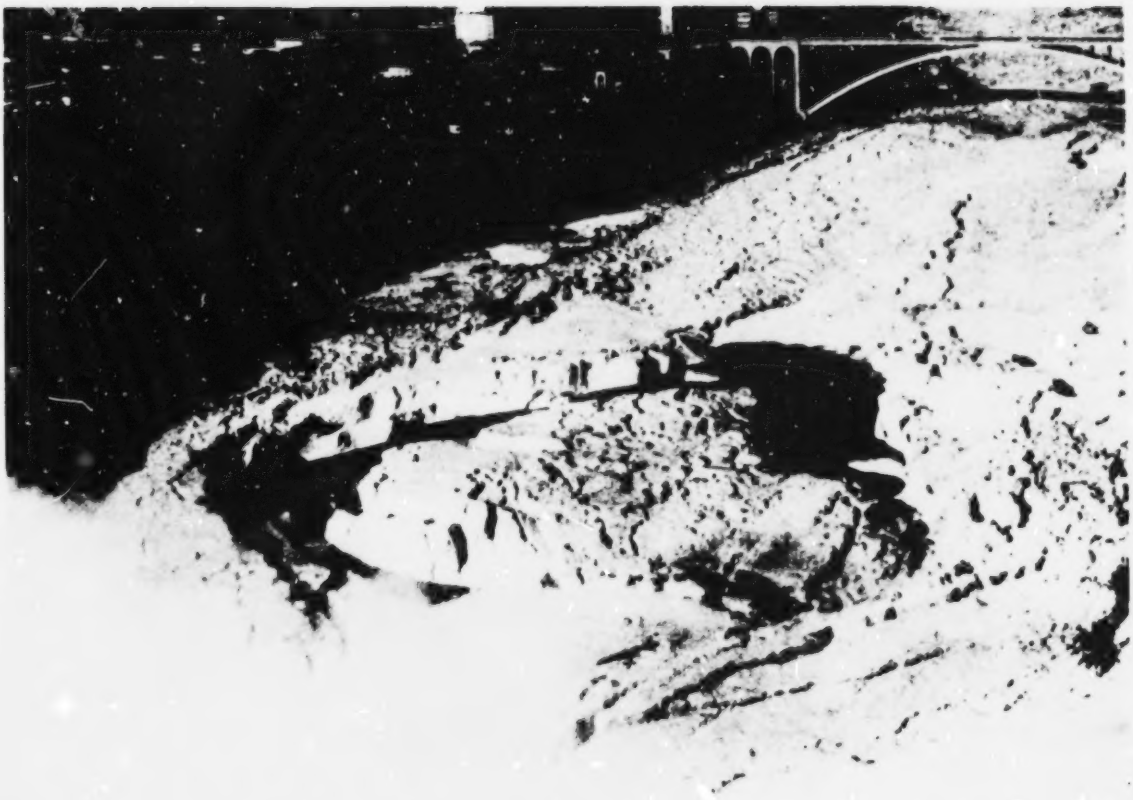
Slide 10 The rising level dislodged shore ice in exactly the same way the spring runoff dislodges shore ice along your streams. The only difference here is the size, as this piece was 300 m long by 30 m wide.

Slide 11

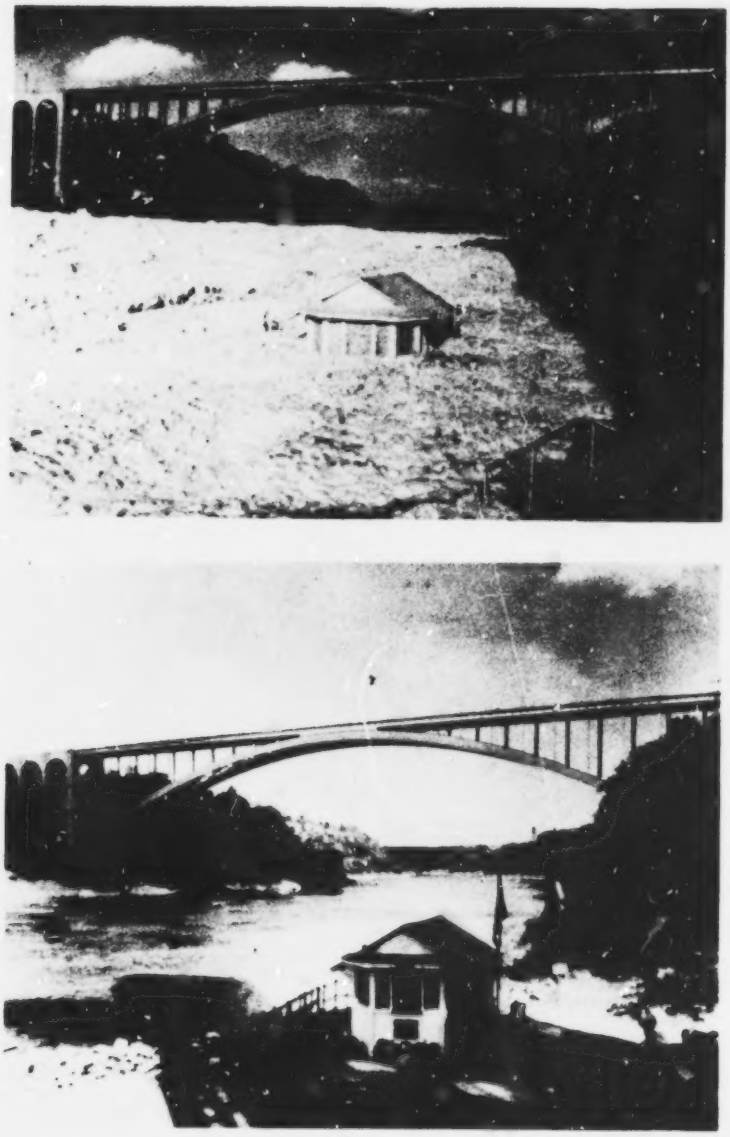
It must pass down-river to the falls or it will cause an artificial ice barrier, as shown in this case. The sluices are only 30 m wide, so the gates must be open enough to create enough current for the big pieces to break up on impact. If the sluices are closed, the ice will pack to the bottom in 20 minutes or less.



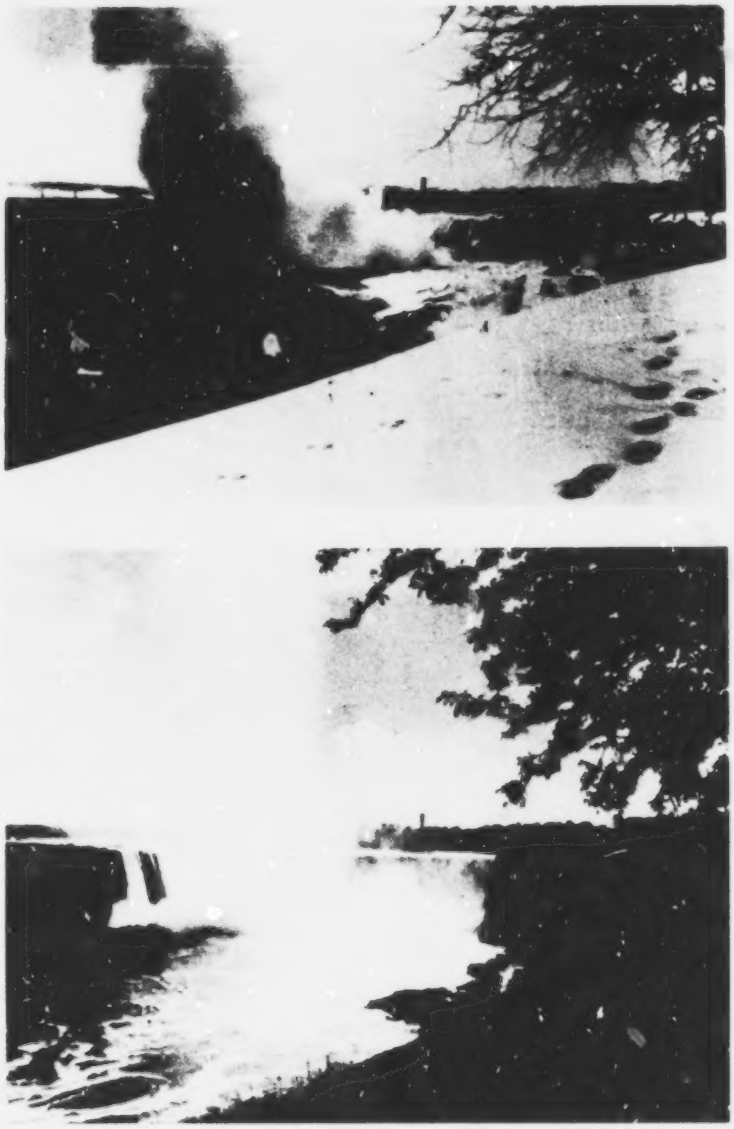
Slide 12 Close-up of some of the gounded ice floes. Water depth 3 m, and ice in Lake Erie nominally 0.5 m thick, but the floes have been thickened by winds, waves, shoving, etc.



Slide 13 Maid of the Mist pool again, after the storm. The vertical face of ice in the middle is about 20 m above the water. During this storm, there was 20 m of differential across the ice jam; i.e., between the water level at the base of the falls and the Whirlpool Rapids 3 km downstream.



Slide 14 Spring and winter comparison of the Maid of the Mist Pool ticket office, and also showing the ice level at the piers of the Rainbow Bridge. The bridge survived because its piers were higher above water than the Honeymoon Bridge, and more particularly because there are two power plants (Sir Adam Beck #2 and Robert Moses) which divert water from the river before it reaches this congested area. At the height of the storm, when the water levels were rising above 2 m/hour, the two generating stations were diverting 2830 cu. m/sec, and there is little doubt that this prevented a major catastrophe on this occasion.



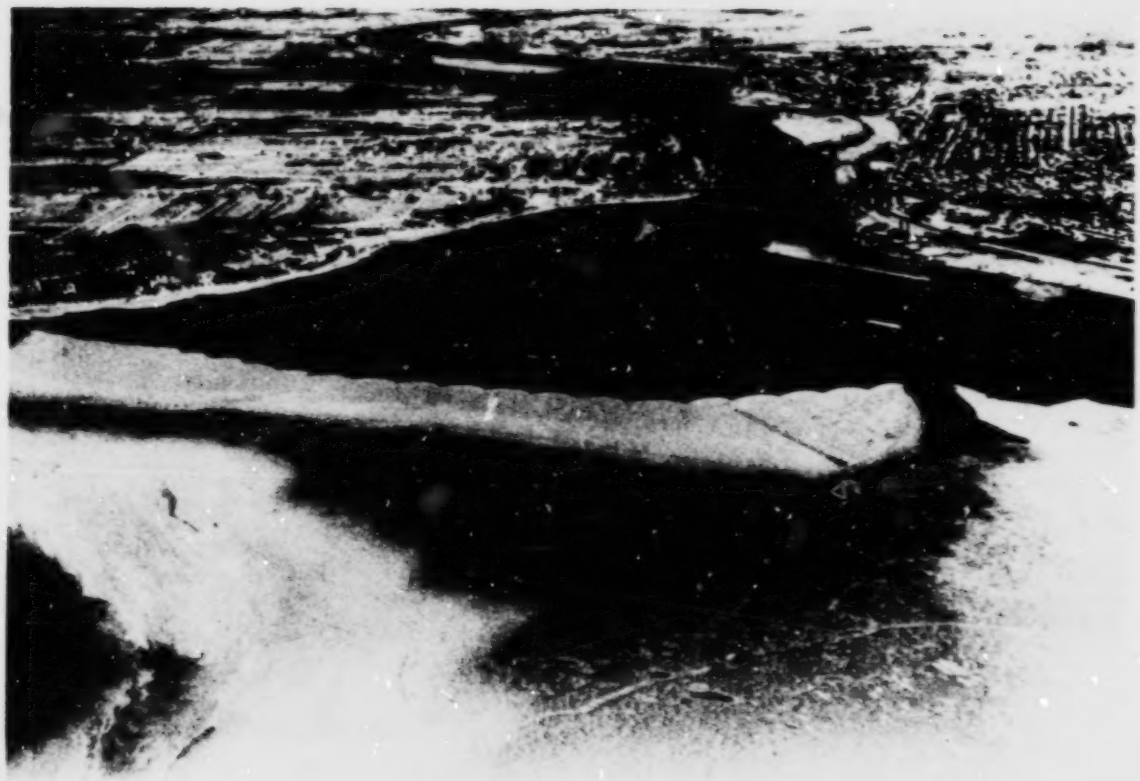
Slide 15 Spring and winter again, showing the height of the winter build-up of ice on the left flank of the falls.

Slide 16

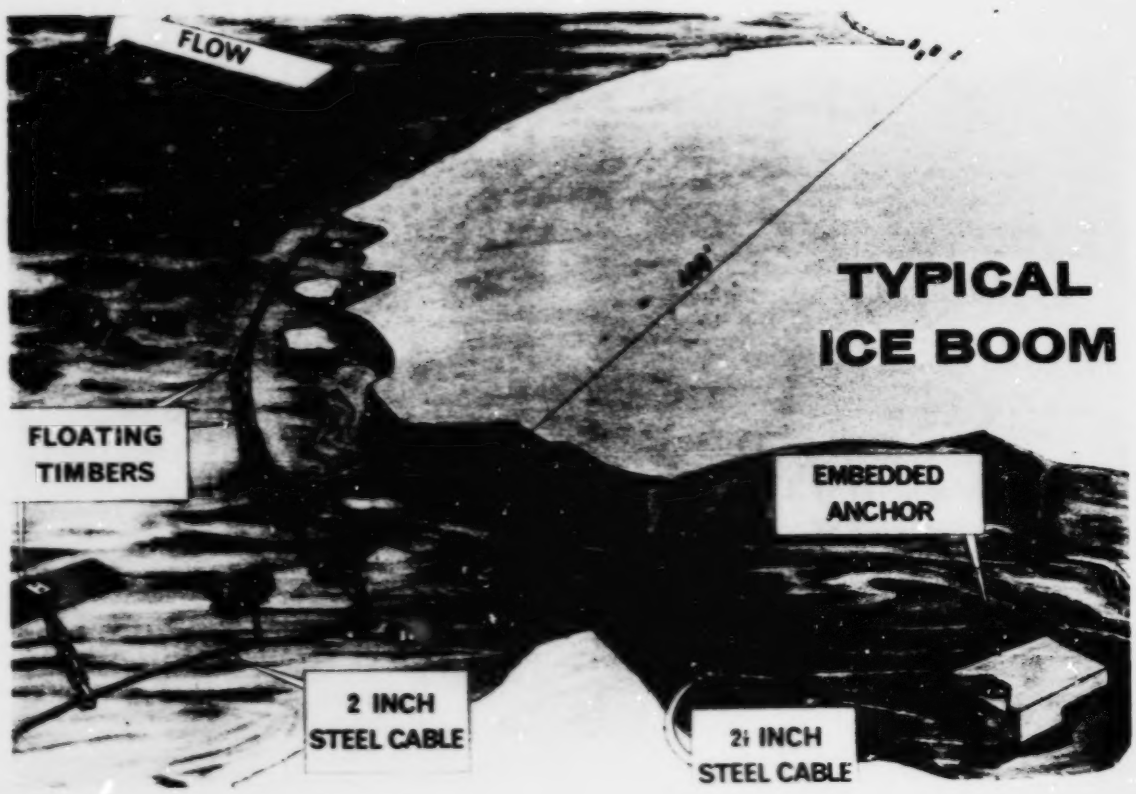
In the lower river, between Queenston and Lake Ontario, there was not enough current to push the ice into Lake Ontario, and a cover formed. An icebreaker was able to break this cover in about a week and prevent another possible disaster in the lower river where the continuous supply of ice being forced under the ice cover was driving water levels at Queenston up at the rate of 1 m/day.

Slide 17

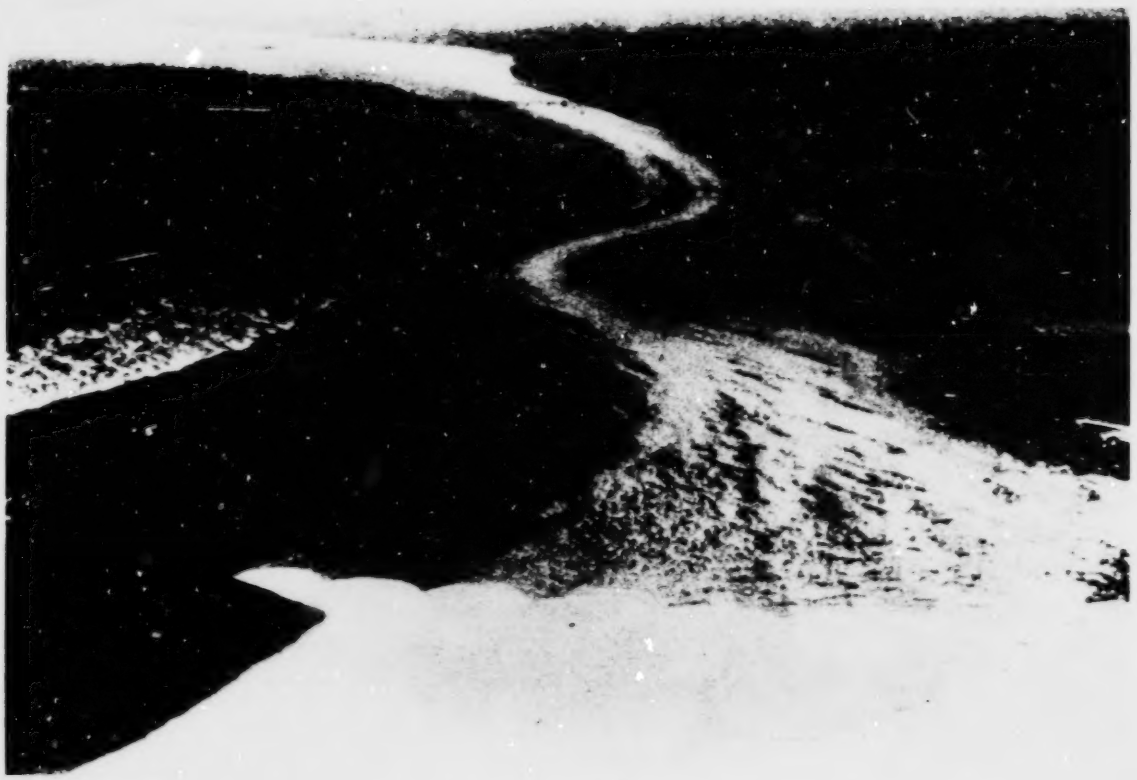
In the upper river, special-purpose ice breakers are used to break up grounded ice - always remembering, if you are in the boat, to make sure that you do not get "hung up" on top. This situation may happen to ice breakers of all sizes when the ice they are breaking is grounded. At such times, the Canadian Coast Guard has found that turning the ship around and backing through the jam is most effective. In fact, the ship literally eats its way through.



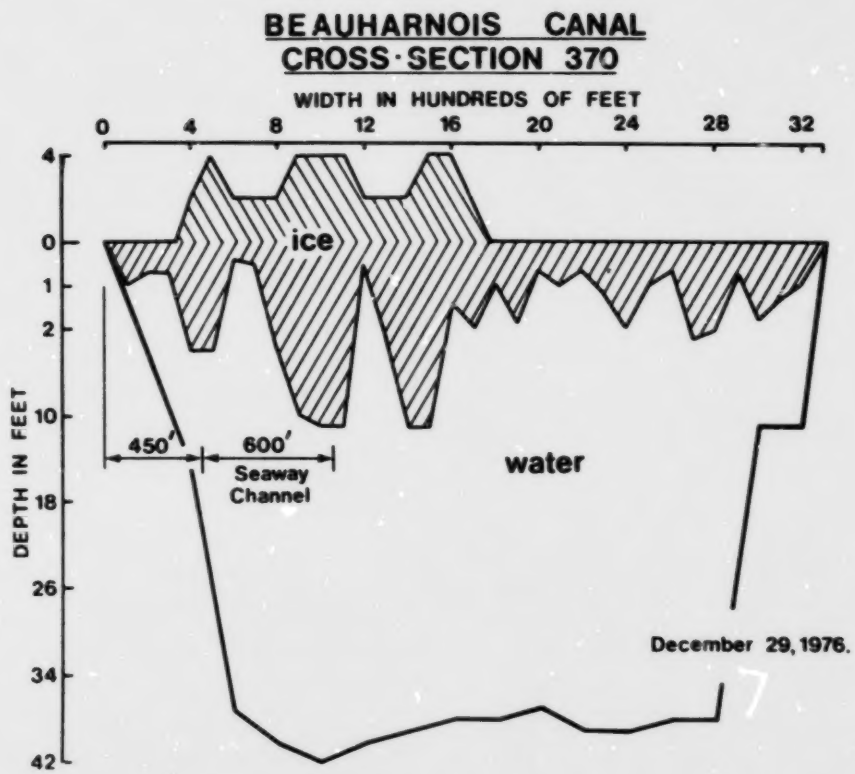
Slide 18 So how do you control ice movement? Use an ice boom. Fort Erie to Buffalo, 3 km in length, located at right angles to the current in velocities of 0.6 m/sec.



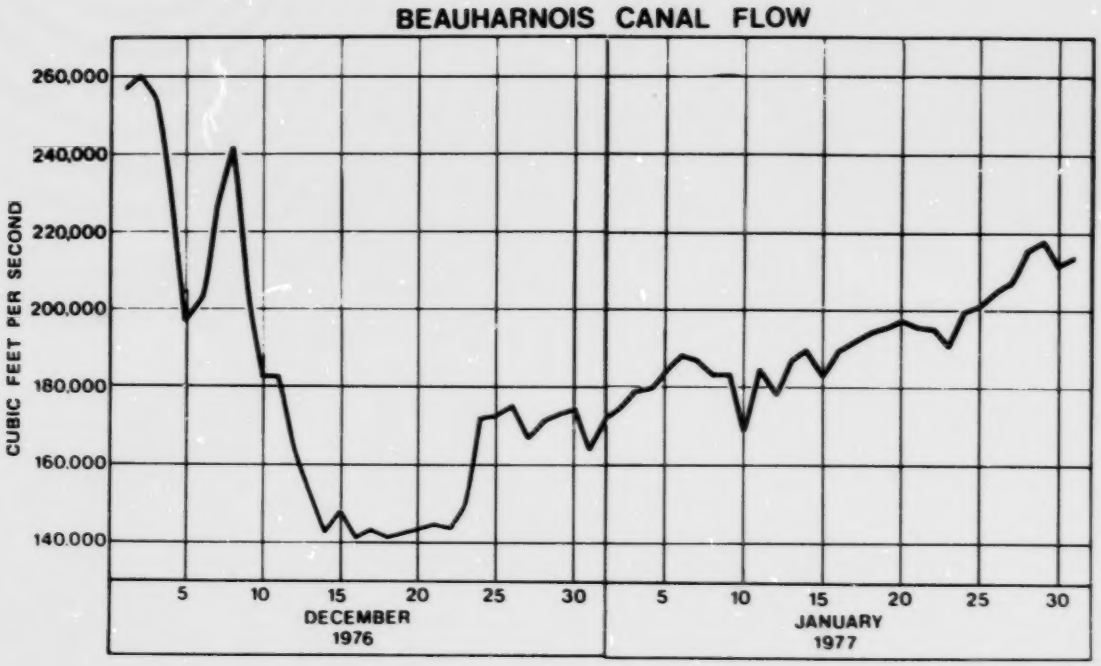
Slide 19 Detail of ice boom showing how the timbers are connected to steel cables which are tied back to anchors on the bottom.



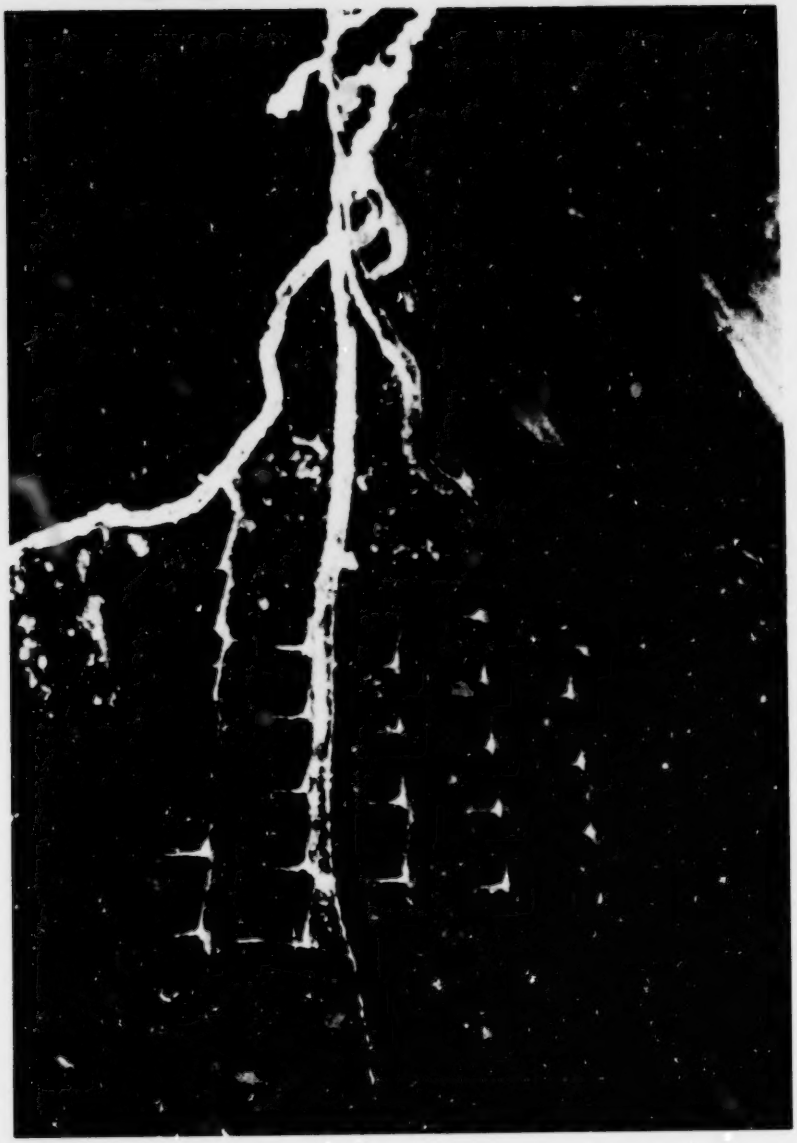
Slide 20 Ice boom spilling due to high velocity flow and winds.



Slide 21 Effects on ice cover thickness of mixing navigation and water control - the ice cover being several times thicker in navigation channel.

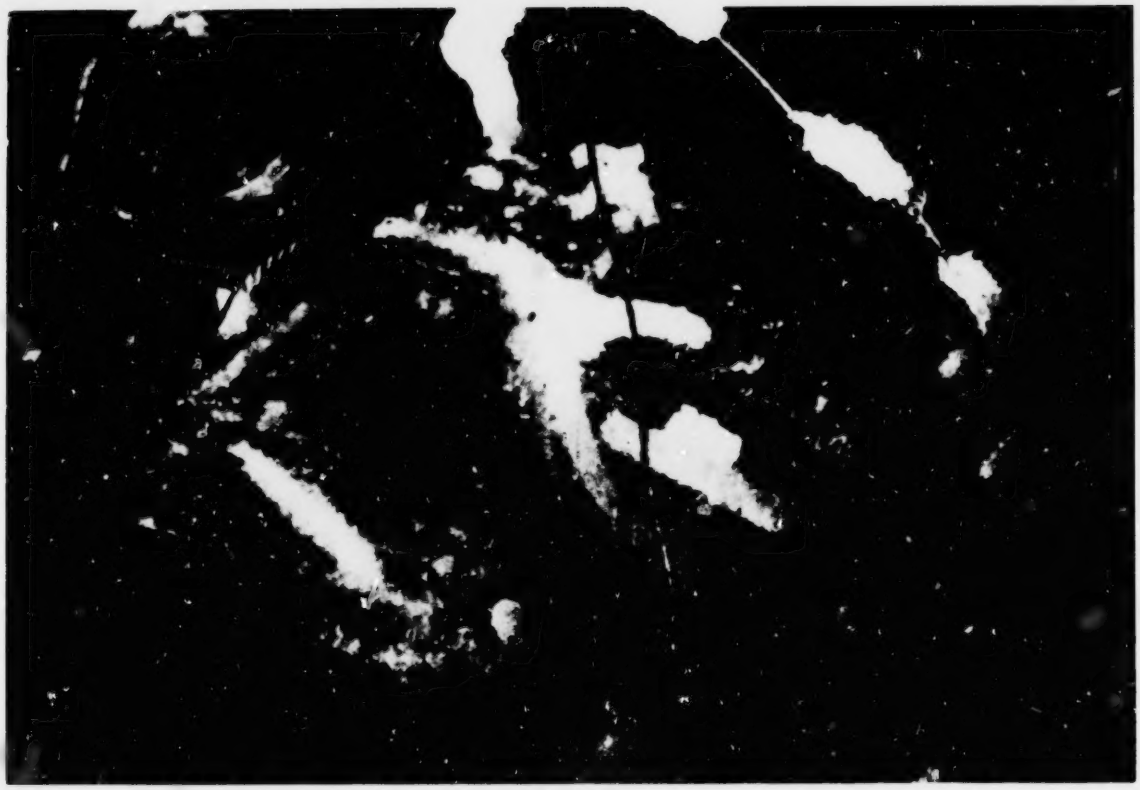


Slide 22 Effect on flows of the thicker ice cover due to navigation - i.e., about 2800 cu. m/sec reduction required. Also note that erosion smoothed off the under side over time, and the flow recovered after a couple of months.

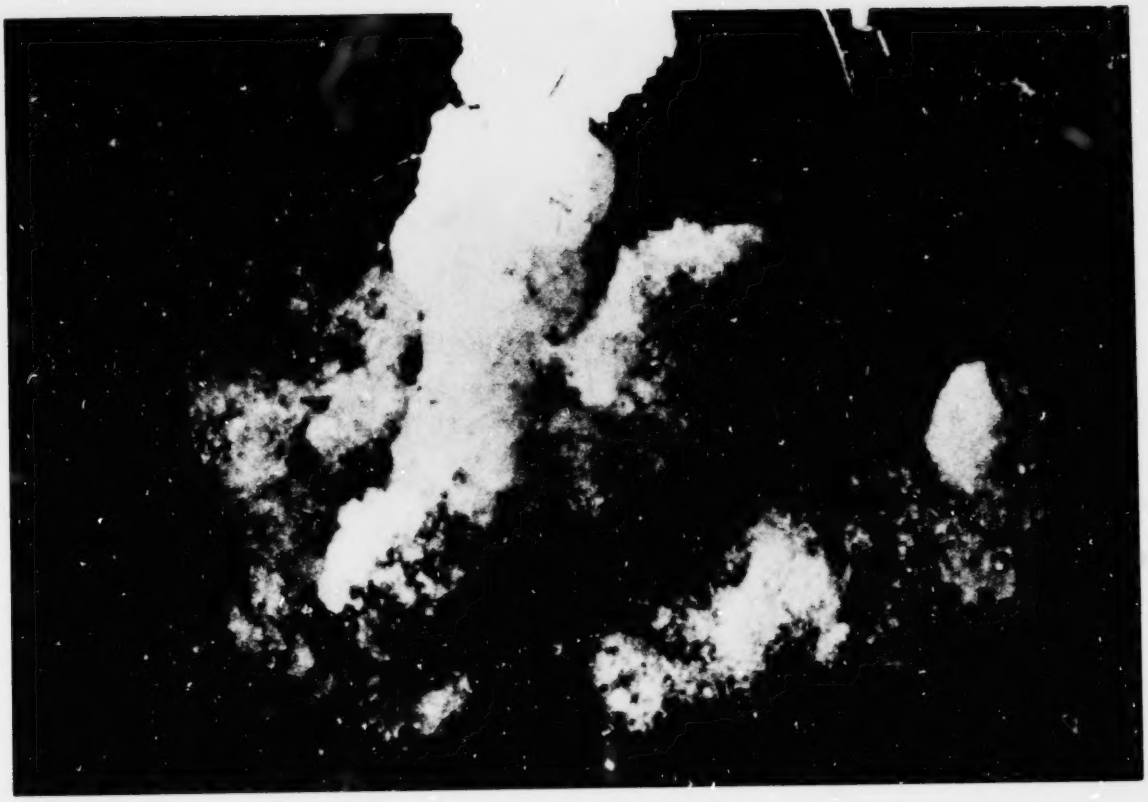


Slide 23

Ice problems of a different kind - frazil and anchor. Tray of angle iron and chain link fence which had been placed on the bottom for 15 minutes, after "super-cooling" of the water had commenced. Super-cooling amounting to about -0.05° C as a result of below freezing air mixing with water.



Slide 24 Same tray after 45 minutes.



Slide 25 Same tray after 90 minutes.

Slide 26 Close up of ice on the tray, showing the millions of small crystals which have grown and attached themselves to one another.

Slide 27 Anchor ice on the bottom rocks - mostly frazil which has stuck to the rocks. In the Niagara River, this stuff can change the discharge capacity by 30% in 4 hours. In some of the smaller streams, it can form so fast and so thick that they appear to freeze from the bottom up!

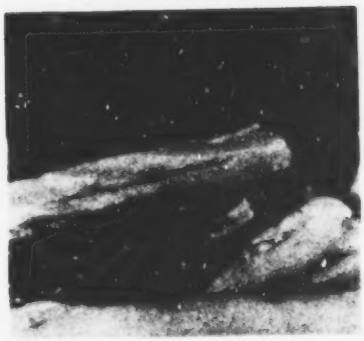
FIGURE 6 PRESSURE RIDGES IN "ICE COVER" AT DOWNSTREAM END OF SLATE FALL
FEB. 16/66

Slide 28 In the more typical streams within Ontario, the areas where problems are to be expected are the downstream end of a long rapids which will look like this. The ridges in this case were several metres above the water.

ICE "VOLCANOE"

FORMED AT BASE OF RAPIDS

ICE LEVEL VIEW OF ABOVE,
HEIGHT 3 METRES
DEPTH 10 METRES



CLOSE-UP OF "FISSURE"

LAYERS SHOW SUCCESSIVE DAYS OF "BREAK-UP" OF ICE COVER ON THE UPSTREAM RAPIDS

MADAWASKA RIVER

5 FEBRUARY 1970

Slide 29 Ice mounds are also found - usually from frazil and slush accumulating, but occasionally like these, where a hydro station upstream is varying the flow from 0 at night to the maximum plant capacity in the daytime.

Slide 30 Belleville's main street in February 1981.

Slide 31 Note blue ice and size of pieces. Both the ice quality and piece size were very bad for passing through the constricted areas.

Slide 32 About 20 minutes later, after the jam broke!

Slide 33

If you discharge to a lake - such as at Port Hope or Dunnville - you may find these ice ridges. This one is in Lake Erie at Nanticoke, looking off-shore, and the ridge occurs at or near the 4 m depth contour. The ice between the 4 m depth and the shore tends to become anchored to the shore, and is called "shore-fast" ice.

Slide 34 Close up of ridge at Nanticoke - typical of the problem when wind-driven sheets come ashore.

Slide 35 Finally, on Lake Huron, a similar "shore-fast" area ridge formed by an on-shore storm when the water was trying to freeze. The spray was coming down as ice and water, and these ridges built up over one week-end - these were 18 m high.

ICE JAMS: ORIGIN AND CONTROL

by

E. Tsykin

Alcoa of Australia Limited

Pinjarra

Western Australia 6208

1. Introduction

Ice jams originate from a number of causes, occur at all hours of the day or night and often in locations which are generally inaccessible. Eye witness observations are infrequent and very seldom documented or related to the weather events which caused the jams. Nevertheless, in Russia there existed a considerable quantity of data, extending over many years, which was considered likely to provide a statistical solution to the causes of ice jams and their control. It is the purpose of this paper to set out the findings of this statistical analysis, recognizing that it uses only those parameters actually observed and thus describes the process only indirectly. The interpretation is therefore subjective, but the main properties of the jamming process are revealed.

2. Main Parameters for Jamming

Two dependent variables were selected as being most important as follows:

Time - speed of the break-up movement, in km/day, for a particular section of a river under study

BW-cv - coefficient of variation of daily backwater on the day of break-up, caused by the intensity of ice jamming.

Other independent variables considered include a number of climatic and hydraulic factors arising from the standard hydrometeorological observations as follows:

I-aver - thickness of ice before break-up

I-cv - coefficient of variation of ice thickness

T-aver - average temperature of air during the break-up

T-sumb - sum of positive temperatures before the break-up

T-suma - sum of positive temperatures after the break-up (five days)

Fl-aver - average volume of the spring flood

Fl-up - volume of spring flood which was measured on the upper border of the studied section of the river

D-aver - average discharge on the day of break-up

D-rat - average ratio of discharge a day before break-up to the discharge a day after break-up

BW-aver - average backwater on the day of break-up

BW-aut - average autumn backwater

ST-amp - average stage amplitude (average difference between a stage before the spring flood and its maximum)

STW-max - average of the highest autumn and winter stages

3. Examples of Application of Multiple Regression

The data for two rivers studied are given in Table I, based on a 35-year period of record.

First, with regard to the Yenisey, a matrix was prepared of the partial correlation coefficients of each of the parameters noted above, and these are shown on Table II.

The methods used to calculate these coefficients are given on Table III.

4. Significance of Variables by Partial Correlation Analysis

Continuing with the Yenisey River example, we find that the two main parameters of time and backwater variation are affected primarily by the factors shown in the equation on the top of Table IV.

Further, from the bottom of Table IV we may note that Time is a function of air temperature during the break-up, the volume of the spring flood and the discharge on the day of break-up. Finally, the backwater coefficient of variation is a function of the average backwater on the day of break-up, the volume of the spring flood, the stage amplitude, the average of the highest autumn and winter stages and the ratio of the discharges the day before break-up to the day after.

The second example, using the Severnaya Dvina River data, is shown on Tables V and VI, with Table V showing the partial correlation coefficients and Table VI showing the important variables in the equations at the top and their significance at the bottom.

5. Causes of Initial Jamming

Analysis of the two examples reveals two main causes of jamming, as follows:

(a) Insufficient ice destructive power of a flood ("D")

(b) Insufficient transportation ability of a flood ("T")

In addition, ice destruction power is made up of:

(c) Power of flood ("P")

(d) Melting ("M")

6. Main Types of Ice Jamming

By combining the initial causes and the main destructive powers, we get four main types of jamming, as shown on Table VII. Here, the causes of jamming are labelled "origin", and the destructive powers "overcoming".

Different types of ice jams require different preventative measures. For example, measures suitable for DP and DM jams can greatly increase TP and TM jams. At that stage, the assessment of the variables makes it possible to find a specific set of effective measures for each combination of main causes of ice jams and powers of destruction.

7. Ice Jam Controls

For the various categories given on Table VII, their suggested remedies are outlined on Table VIII.

8. Conclusions

The assessment of the relative significance of the various parameters was established by statistical correlation, assisted in part by 35 years of experience with the rivers used in the examples. It is suggested that this method could be used to provide a preliminary assessment of any river as to the type of jam to be expected and also of the river's ability to cope with the problems or, alternatively, of the type of assistance that would likely be required.

It may be of interest to note that neither example included ice thickness parameters as being particularly important.

EDITORS' NOTE: We noted that T-SUMB, air temperature prior to break-up, was also not important, and we found this hard to believe. A request for clarification by the author was made, but without success.

TABLE I

BASIC DATA FOR YENISEY AND SEVERNAYA DVINA RIVERS

	YENISEY	SEVERNAYA DVINA
Annual flow, km^3	591	107
Catchment area, km^2	2,500,000	350,000
Length of studied section, km	1,737	400
Speed of break-up movement, km/day	48	54
Ice jamming intensity (BV-cv)	0.76	0.62
Average ice thickness, cm	90	62
Average air temperature during the break-up, C^o	2.7	4.2
Sum of positive temperatures before the break-up, C^o	30 (0.3)	44 (0.7)
Sum of positive temperatures after the break-up (5 days)	17 (0.2)	26 (0.4)
Average backwater on the break-up day, cm	192	96

TABLE II

YENISEY RIVER

Matrix of partial correlation coefficients ρ

	TIME	l-aver	l-cv	T-sum	FL-aver	D-aver	D-rat	BW-aver	ST-grp	BW-cv	T-aver	FL-up	T-sumo	BW-out	Mult Corr. Coef. STW-max	R
TIME	1	-	.25	-	.17	- .30	-	-	- .17	-	- .35	- .52	-	- .17	.23	.3699
l-aver	-	1	- .15	- .21	.23	-	-	-	.29	-	.40	.29	- .29	.22	- .27	.7334
l-cv	.25	- .15	1	.26	- .33	.22	- .31	-	-	-	-	.24	- .30	-	-	.7269
T-sumb	-	- .21	.36	1	.43	-	- .16	-	.23	-	.52	.27	- .18	-	-	.8963
FL-aver	.17	.23	- .33	.43	1	.61	- .17	-	-	.22	- .34	-	.23	-	-	.8131
D-aver	- .30	-	.32	-	.61	1	-	-	-	- .27	-	- .21	-	-	-	.7588
D-rat	-	-	- .31	- .16	- .17	-	1	-	.29	- .29	.28	.23	- .26	-	-	.7229
BW-aver	-	-	-	-	-	-	-	1	.65	- .63	- .26	.45	.39	- .26	- .19	.9000
ST-grp	- .17	.29	-	.23	-	-	.29	.65	1	.49	-	.30	- .32	-	.45	.8795
BW-cv	-	-	-	-	.22	- .27	.29	- .63	.49	1	-	.42	-	- .20	- .27	.8477
T-aver	- .35	.40	-	.52	- .34	-	.28	- .26	-	-	1	- .30	.85	- .34	-	.9758
FL-up	- .52	.29	.24	.27	-	- .21	.23	.45	- .30	.42	- .30	1	-	-	.18	.8452
T-sumo	-	- .29	- .30	- .18	.23	-	- .26	.39	- .32	-	.85	-	1	.28	-	.9646
BW-out	- .17	.22	-	-	-	-	-	- .26	-	- .20	- .34	-	.28	1	.57	.8571
STW-max	.23	- .27	-	-	-	-	-	- .19	.45	- .27	-	.18	-	.57	1	.8442

TABLE III

CALCULATION OF COEFFICIENTS OF VARIATION

$$CV = \sqrt{\frac{\frac{(x - \bar{x})^2}{n - 1}}{\bar{x}}} = \frac{\sigma}{\bar{x}}$$ Coefficient of variation

$$\rho = \sqrt{1 - \frac{1 - R^2\,(abcd)}{1 - R^2\,(bcd)}}$$ Partial correlation coefficient

X_1	X_2	X_3	X_4	X_5	n	$\bar{x}$	σ	CV
1	1	1.2	1	1	5	1.04	.09	.09
1	1	2.0	1	1	5	1.20	.45	.37
1	1	3.0	1	1	5	1.40	.89	.64
1	1	5.0	1	1	5	1.80	1.79	.99
1	1	8.0	1	1	5	2.40	3.13	1.30
1	1	12.0	1	1	5	3.20	4.92	1.54

TABLE IV

YENISEY RIVER

Time = 145 - 0.13 Taver - 0.2 FLup - 0.12 Daver, R = 0.85;
BWcv = 194 - 1.05 BWaver + 0.33 FLup - 1.06 STamp - 0.8 STWmax - 0.48 Drat
R = 0.80

ρ

	TIME	BW-cv
TIME		-
BW-cv	-	-
I-aver	-	-
I-cv	.3	-
T-aver	- .4	-
T-sumb	-	-
T-suma	-	-
FL-aver	.2	.2
FL-up	- .5	.4
D-aver	- .3	- .3
D-rat	-	.3
Bw-aver	-	- .6
BW-aut	- .2	- .2
ST-amp	- .2	.5
STW-max	.2	- .3

DTM

$$TIME = f(-T_{aver}^{T}, -FL_{up}^{TM}, -D_{aver}^{T}).$$

$$BW\text{-}cv = f(-BW_{aver}^{D}, FL_{up}^{D}, -ST_{amp}^{D}, -STW_{max}^{D}, -D_{rat}^{D}).$$

TABLE V

SEVERNAYA DVINA RIVER

Matrix of partial correlation coefficients ρ

	TIME	I-aver	I-cv	T-sum	FL-aver	D-aver	D-rat	BW-aver	ST-arp	BW-cv	T-aver	FL-up	T-sumb	BW-aut	Mult Corr. Coef. STW-max	R
TIME	1	-	-	- .26	-	.16	-	-	-	.50	- .18	.32	- .48	- .38	.34	.9294
I-aver	-	1	-	.23	.20	.21	-	- .16	-	.40	.17	.20	- .33	-	.28	.7118
I-cv	-	-	1	-	-	.22	-	-	-	-	.15	-	.22	.34	-	.6570
T-sumb	- .26	.23	-	1	- .35	.31	.57	.51	.59	-	.53	- .34	.16	.41	.27	.8723
FL-aver	-	.20	-	- .35	1	.34	- .34	- .39	.43	-	- .30	.91	- .23	.45	.44	.9807
D-aver	.16	.21	.22	.31	.34	1	- .25	-	.35	.17	.45	.47	.37	.52	.48	.8211
D-rat	-	-	-	.57	- .34	- .25	1	.58	.56	- .15	.30	- .36	-	.24	- .15	.8715
BW-aver	-	- .16	-	.51	- .39	-	.58	1	.59	- .50	.42	- .33	-	.17	-	.9322
ST-arp	-	-	-	.59	.43	.35	.56	.59	1	-	.59	.38	-	.18	-	.8955
BW-cv	.50	.40	-	-	-	.17	.15	- .50	-	1	- .18	-	- .22	-	- .43	.9210
T-aver	- .18	.17	.15	.53	- .30	.45	.36	.42	.59	- .18	1	- .42	.62	- .37	-	.8991
FL-up	.32	.20	-	- .34	.91	.47	- .36	- .33	.38	-	- .42	1	- .38	.58	.45	.9830
T-sumb	- .48	- .33	.22	.16	- .23	.37	-	-	-	- .22	.62	- .38	1	- .44	.34	.8328
BW-aut	- .38	-	.34	.41	.45	.52	.24	.17	.18	-	- .37	.58	- .44	1	.57	.8451
STW-max	.34	.28	-	.27	.44	.48	- .15	-	-	- .43	-	.45	.34	.57	1	.8775

TABLE V!

SEVERNAYA DVINA RIVER

TIME = 36 + 0.53 FLaver + 0.43 BWCV - 0.32 TSUMA, R = 0.90
BVcv = 88.5 - 0.76 BWaver + 0.54 TIME + 0.33 Taver, R = 0.88

	TIME	BW-cv
TIME		.5
BW-cv	.5	-
I-aver	-	.4
I-cv	-	-
T-aver	- .2	- .2
T-surb	- .3	-
T-suma	- .5	- .2
FL-aver	-	-
FL-up	.3	-
D-aver	.2	.2
D-rat	-	- .2
Bw-aver	-	- .5
BW-aut	- .4	-
ST-amp	-	-
STW-max	.3	- .4

TIME = f (FL-aver, BW-cv, - T-suma, -BW-aut)

BW-cv = f (- BW-aver, TIME, T-aver

and I-aver, - STW-max)

TABLE VII

MAIN TYPES OF JAMMING

OVERCOMING \ ORIGIN	Shortage of power to destroy ice cover 'D'	Shortage of transportation ability 'T'
mainly by power 'P'	DP	TP
mainly by melting 'M'	DM	TM

TABLE VIII

ICE JAM CONTROLS

D	1.	Autumn level monitoring by damming or clearing side channels.
DM	2.	Ice dusting.
	3.	Furrowing of ice cover.
	4.	Use of ice breakers (preliminary).
	5.	Spring water level monitoring by damming or clearing side channels.
	6.	Blasting of ice cover.
	7.	Blasting and bombing ice jams.
	8.	Use of ice breakers during the break-up.
TP		Far above the protected zone: *
TM	1.	Construction of artificial ice jams.
	2.	Keeping natural ice jams.
	3.	Increasing of warm floods from south.
	4.	No DP and DM measures.
		Within the protected zone:
		All the DP and DM measures.

* EDITORS' NOTE: Something seems to be missing.

ICE JAM MONITORING IN THE GRAND RIVER BASIN

A CASE STUDY

by
Paul Frigon

Grand River Conservation Authority

There are newspaper records of significant ice jam events in the Grand River Basin from the middle of the 1800s to current times. Up until the middle of the 1930s, the majority of damaging ice jams occurred at the cities of Galt and Brantford, with occasional reported ice jams in smaller urban areas such as Dunnville, Grand Valley and Bridgeport (see Figure 1).

From the early 1950s to date, damaging ice jams in the larger communities have been non-existent; most likely due to increased flow carrying capacities of bridge and rail crossings and changing climatic conditions. It is also probable that flow control by reservoirs during spring break-up has considerable effect on the rate at which the ice cover breaks up and thus on the size and density of resulting ice floes. The reservoir system in the Grand River Basin was first implemented with the construction of the Shand Dam in 1946, followed by the Conestogo Dam in 1954 and the Guelph Dam in 1975 (see Figure 1).

The last four years have seen an increase in the frequency of damaging ice jam events in southern Ontario in general. In the Grand River basin, there have been five significant ice jams in the last four years; two in Paris (1979, 1981) and one each in Dunnville (1981), Grand Valley (1982) and West Montrose (1981).

While data collection and monitoring of ice jam characteristics is still in its formative stages at the GRCA, there already exists a large monitoring network that can meet some of the needs for ice jam prediction and prevention. In addition, an effort is being made to monitor more rigorously such elements as ice thickness, degree days of thaw to break-up, stage at freeze-up and ice jam profiles.

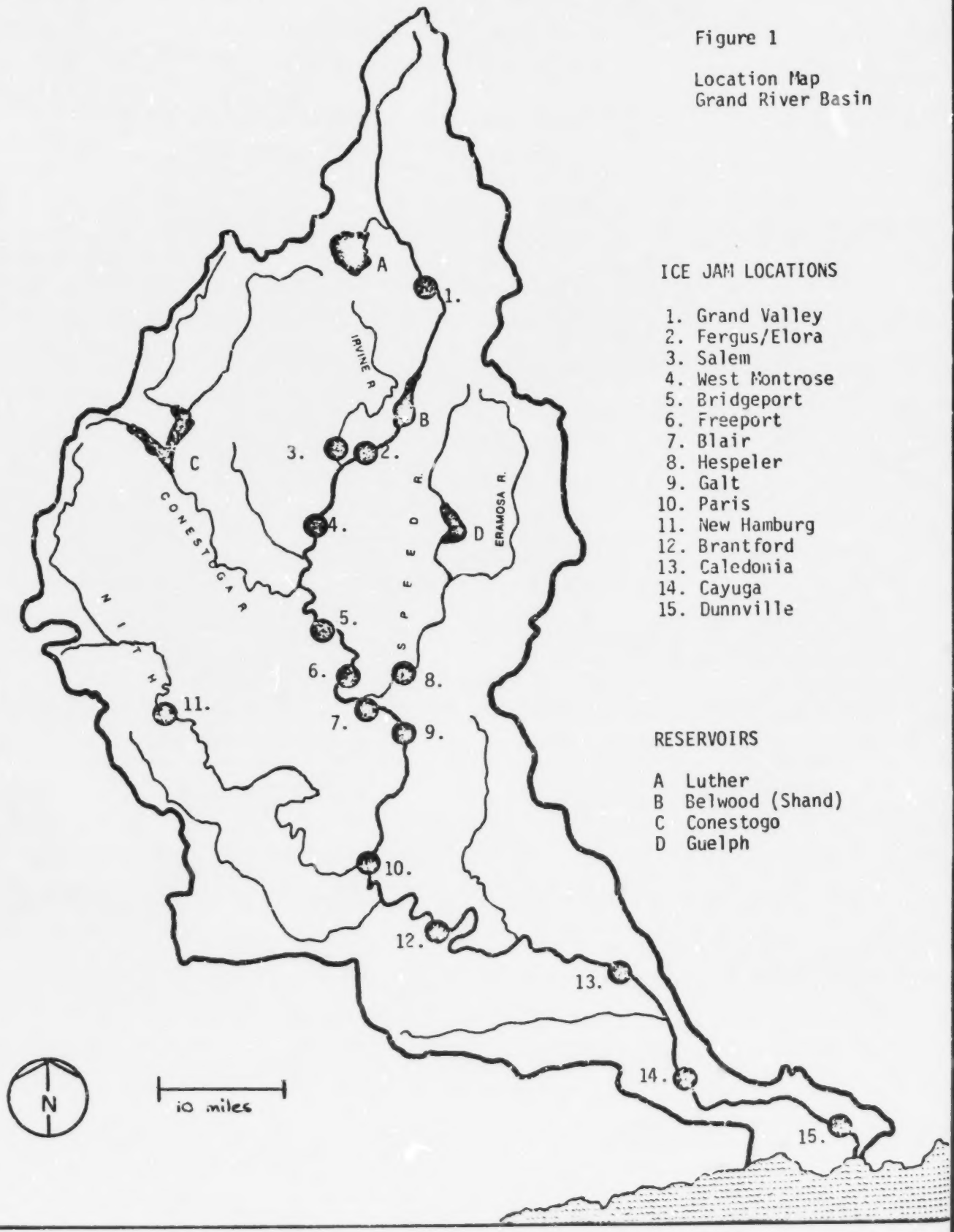


Figure 1

Location Map
Grand River Basin

ICE JAM LOCATIONS

1. Grand Valley
2. Fergus/Elora
3. Salem
4. West Montrose
5. Bridgeport
6. Freeport
7. Blair
8. Hespeler
9. Galt
10. Paris
11. New Hamburg
12. Brantford
13. Caledonia
14. Cayuga
15. Dunnville

RESERVOIRS

A Luther
B Belwood (Shand)
C Conestogo
D Guelph

Presently, ice thickness is measured most frequently by the Water Quality Division of GRCA during their bi-monthly water quality sampling runs throughout the basin. This gives a rough estimate of the thickness and strength of ice at various times and locations in the system, but is not as consistent as measuring ice thickness at exactly the same time and place each year.
The formation, location and movement of ice covers, ice floes and ice jams throughout the river system is recorded to some degree by a River Watch using GRCA field personnel. The basin is subdivided into 14 areas represented by either a dam operator or conservation area superintendent who is familiar with his particular area. Reports are sent in monthly indicating the extent of ice cover, comments on its structure and formation and, in some locations, ice thicknesses are measured. As winter progresses into spring, the reports become weekly and may even be daily if requested by flood forecast personnel at headquarters. Known ice jam locations are patrolled frequently.

The River Watch has been expanded in the Paris-Brantford and Lake Belwood-Grand Valley reaches of the Grand River. This is in co-operation with the Canada Centre for Inland Water's (CCIW) long-term field research program started in 1979. Emphasis has been placed on the recording of ice jams through photographs and any measurements that can be taken at the time, such as staff gauge heights, estimates of jam length, descriptions of the toe, and status of the jam (grounded or floating). The photographs enable survey crews to record the jam profile during the summer months. These field observations may identify important physical mechanisms that can be studied by theory and laboratory experimentation by such institutions as the CCIW.

Monitoring is also carried out on snowpack densities (bi-monthly), precipitation and temperature. River stage is also monitored by recording gauges and staff gauges throughout the basin. It is fortunate that four ice jam sites are located near recording gauges: Waldemar, Upper Belwood, West Montrose, and Doon. Only one of these, West Montrose, has any serious problems as a result of ice jamming. Two other sites that have ice jam problems, Paris and Grand Valley, have staff gauges to record maximum water levels.

All of this information should begin to provide quantitative field data for testing and calibrating existing theory in ice jam prediction and prevention. Such systematic observations of annual break-up are necessary so that at least statistical records may be created, probabilities of events assigned and, hopefully, more reliable methods of ice jam predictions and prevention will eventually result.

A look at the ice jam events at West Montrose in February 1981 will help to illustrate some of the above discussion on monitoring ice jams.

The ice jam occurred at West Montrose on February 23, 1981. This was the month that experienced a rapid thaw from the 16th on. Break-up at Bridgeport, below West Montrose, occurred on February 19, after roughly 12 degree (C) days of thaw. On February 20, ice was still intact from West Montrose to the confluence with the Conestogo River (see Figure 1), a distance of roughly five miles. Also on February 20, the water stage at West Montrose had reached just over 8 feet, and flooding was imminent (see Figure 2). The GRCA reduced the flow at Shand Dam to 100 cfs in order to avert the flooding. On February 22, flow started to increase as the flow in the uncontrolled Irvine Creek above West Montrose started to rise. On February 23, at 0600 hours, ice from Irvine Creek jammed at West Montrose, causing a three foot rise in the water level that immediately flooded five houses on the east bank of the river.

Ontario Provincial Police responded to local calls for assistance, and the GRCA duty officer was notified, both by the OPP and staff that had arrived early for work and had observed the change in stage on the telemetered gauge at GRCA headquarters.

Another 1.5 foot rise in stage around midday caused some concern that the historic West Montrose covered bridge would be destroyed by the ice that was jamming higher and actually touching the underside of the structure.

A local blasting crew was contacted at 0930 hours and, by 1030 hours, was at the site. At first, there was still two miles of ice cover downstream of the jam but, as the flows from the Irvine River increased, this cover began to break up and move downstream. This final break-up occurred after 28 degree (C) days of thaw.

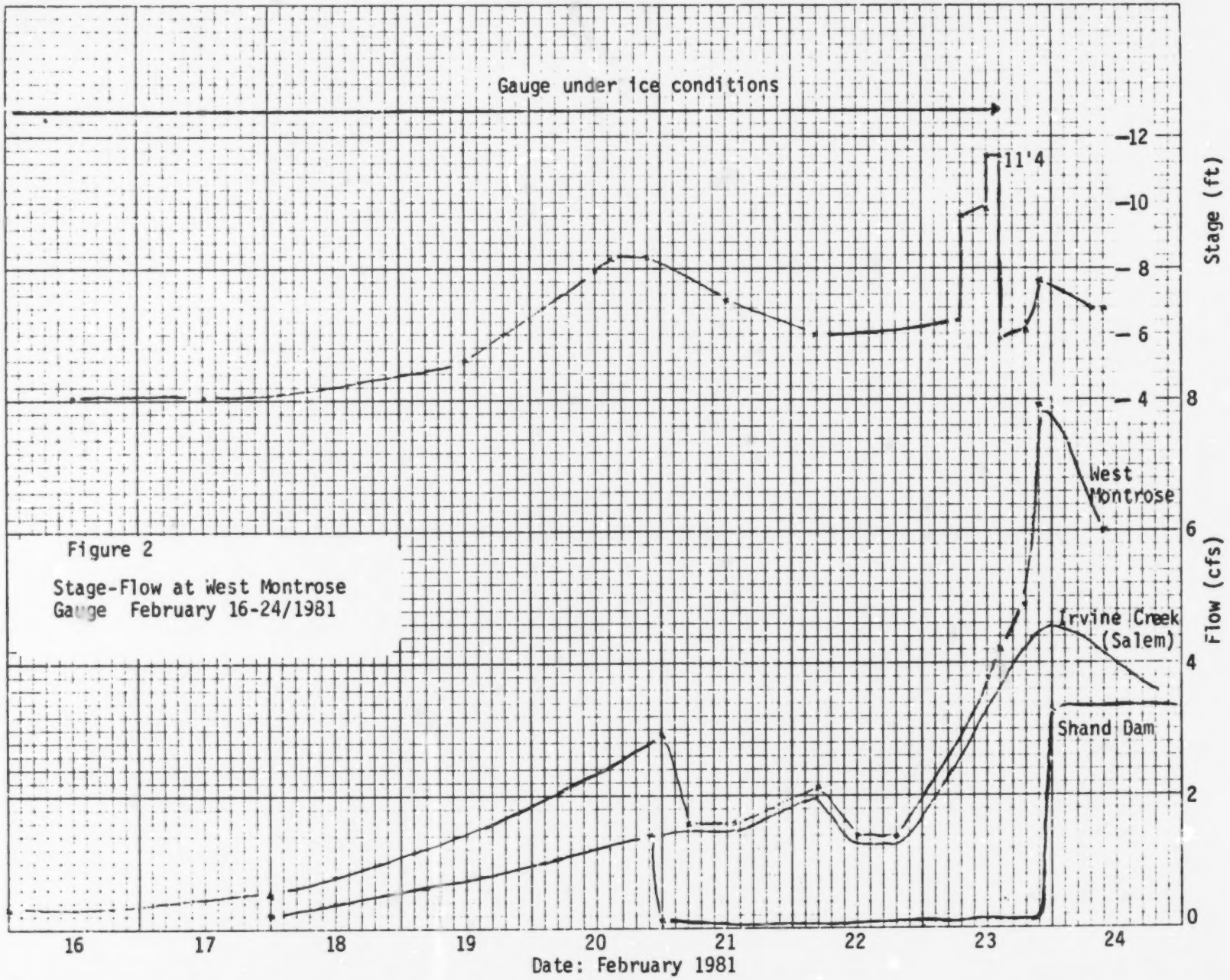


Figure 2

Stage-Flow at West Montrose Gauge February 16-24/1981

Immediately below the jam, four or five charges of dynamite were detonated below the remaining ice cover before the main jam was blasted. The final charge was placed under the toe of the jam by a pike pole roughly 150 feet from the west bank. The blast did not seem to have any immediate effect and roughly a minute elapsed before the jam slowly released from the east bank.

The cause of the jam was the thick, intact ice cover below the bridge. This cover is immediately upstream of a constricted and shallow section of the river that aids in forming an obstruction through grounding of the ice cover. Measurements of ice thickness in 1982 at the site indicated that ice was twice as thick upstream of the constriction as it was in the constriction and that, in the shallows, the ice cover was nearly grounded.

Two immediate solutions are obvious. One is to remove the constrictions and shallows by excavation of roughly 7000 cubic yards of gravel and maintain the channel on a regular basis. The other is to preblast the ice cover at the site if conditions indicate that jam potential exists.

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Principles of Ice Control

by
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This afternoon, I'm going to talk about one section of the Ice Management Manual - the one on Principles of Ice Control. There are copies of the second draft of the Manual available on the table at the back of the room, and I'll be talking about Section VII.

The sections which precede this one cover such things as Causes of Jams, Monitoring of Ice Jam Floods, Remedial Measures which work, and Predictive Techniques for Break-up. Feel free to ask questions as I go along if there are any points which are not clear.

1. CREATE ICE COVER AS SOON AS POSSIBLE

The purpose of an ice cover is to insulate the water from the much colder, below-freezing air. Once ice begins to form, it may reach a thickness of 5 to 10 cm overnight. Its growth thereafter is progressively slower, as the cold must penetrate the ice to the water. It is also greatly affected by snow on the ice cover; snow depths equal to one-half the ice thickness may stop ice thickening completely!

Snowfall on the open water which is trying to freeze will produce slush ice in vast quantities. It is like wet cotton batting in consistency, is extremely difficult to handle, and is very prone to causing flow restrictions.

Where the velocity is fast enough to prevent ice cover, the open water areas continue to create ice for most of the winter and, in our climate, we could expect each square metre of water to produce about 2 cubic metres of ice. On the other hand, the ice-covered areas of slower velocity will only produce a thickness of about 0.5 metres, or roughly 25% of the ice produced by the open water.

If there is no ice cover, the water can become super-cooled to about -0.05C by the air mixing with the water. When this happens, an ice particle blizzard occurs, and the particles are called "FRAZIL". This is the stuff that sticks to everything it touches,

including itself, and can build up very rapidly indeed, especially on a rocky bottom. When this occurs, the water carrying capacity of the river can decrease by 30% in a period of 3 to 4 hours.

2. CONTROL ICE MOVEMENT BY CONTROLLING FLOW AND VELOCITY

Break-up is caused by the rate of change in water level. A 1-metre rise in 24 hours will cause considerable break-up. By controlling the increase in flow, the rate of rise in levels is automatically controlled as well.

Wherever velocities are equal to, or greater than 1 metre/second, break-up will begin, and again controlling the flows will limit the number of areas where such velocities will occur.

This solution is expensive but reliable, as evidenced by the St. Lawrence Seaway and Power Project over 24 winters of operation. It was designed to form ice cover at velocities up to 0.7 m/sec. over most of Lake St. Lawrence. If weather conditions do not co-operate, the flow can be adjusted to compensate, and most of the ice formed will stay on the surface rather than forming a hanging dam.

It may be of interest to note that, prior to this power development, the ice production capacity of the Long Sault Rapids caused huge ice jams downstream of Cornwall. The resulting rise in levels was enough to cause flooding on the main street of the city which was about 15 metres above normal river levels.

3. PROVIDE ICE MOVEMENT CONTROL

Where flow control is too expensive, a lot can be done by controlling the quantity of ice moving into constricted portions of the river.

Ice Booms - When placed at right angles to the prevailing flow direction, and in an area of relatively low velocity such as upstream of a constriction or a weir, ice booms can accelerate the rate of formation of ice cover. In addition, booms will retain ice

cover in the springtime, even if the water level rises considerably, as they should be designed to float up with the rising levels.

When overloaded by ice pressure, they should be allowed to submerge rather than break and, as soon as the pressure becomes less than the buoyancy, they will surface again and cut down the amount of ice movement.

Ice Islands - Man-made or natural, islands provide something for the ice cover to push against after rising levels have removed the restraint formerly provided by the shore. They are not as flexible in their capabilities as ice booms, but have worked well in some instances.

Ice Storages - The best examples of such areas are the Minesing Swamp on the Nottawasaga River and some of the disused channels on the Goulais River. The latter are often located on the outside of sharp bends in the river channel and, as ice tends to go straight ahead rather than following river bends, these former channels fill with ice and act as safety valves for storing a good deal of the broken ice.

4. TIME

By slowing the rate of rise in levels, and by slowing the increase in velocity, the ice broken per kilometre will be reduced and there is, therefore, less ice and water mixture competing for space simultaneously.

As an example, consider the Niagara Gorge situation in 1938 and 1964 when there were major ice jams in both years in the Maid of the Mist Pool. In 1938, all but 470 cu. m/sec of the flow from Lake Erie was passing under the jam, and the levels rose so much that the Honeymoon Bridge was forced off its foundation and collapsed onto the ice. In 1964, the ice quantity was at least as great as in 1938, but 2800 cu. m/sec of the flow from Lake Erie was being diverted around the jam via the tunnels leading to the Sir Adam Beck and Robert Moses plants. It can be shown that this reduced the head on the jam by at least 30%, and there was no disaster.

Time can also help in relation to weather. For example, during freeze-up, a sudden cold spell may cause super-cooling and masses of frazil and jamming, but the normal weather pattern provides for moderation after a few days and the problem will abate and often disappear. Alternatively, the onset of mild weather during break-up, which starts the melting process going, may be followed by colder weather which slows the process down again, providing more time for melting and eroding ice, and a longer period for the ice and water mixture to find its way through the constrictions.

Time is important in another way if you are trying to break a jam, in that such work usually requires daylight, and only 8 to 9 hours of daylight are available each day, whereas the melting and ice break-up activities may be going on continuously.

5. PREVENTION IS MORE EFFECTIVE THAN CURE

Jams can form in half an hour, and take 6 to 8 weeks to remove if they happen in the early winter. The results are reduced flow capacity and possible flooding, neither of which could be tolerated in either the Niagara or St. Lawrence projects.

The solution was to prevent, or at least limit, the amount of potential ice jamming. In the St. Lawrence, a combination of flow control at critical times and ice booms for particular trouble spots has been effective. In the Niagara, an ice boom together with ice breakers has done the job. In both cases, there was also a great deal of excavation to streamline the water (and ice) movement at possible trouble spots such as shallows or bends.

6. WHERE WILL A JAM GO IF YOU BREAK IT?

Knowing the answer to this question is probably the most important factor of all. To be "safe", there should be a large storage area such as a lake or a swamp, or waterfall. Don't just move your problem downstream, as on the Rideau River in 1982, where the Ottawa River normally provides a large enough storage area for the ice from the Rideau. In this case, the Ottawa itself was so ice covered that the ice from

the Rideau had nowhere to go, and did its best to flood back over the falls! (See Figures 1 and 2).

If you're going to break a jam, start at the downstream end and work upstream, which will normally mean starting at the mouth and working upstream. Reasons for this practice are safety to the workers and the desirability of having some flow to move the broken ice away from the work area.

7. BEND IT TO BREAK IT

Ice is weak in bending, and breaks most readily this way whether it is done by ice breakers, air cushion vehicles or waves.

Normal ice breakers press down on the cover to break it, and this works well as long as the cover is floating. A fairly recent experiment used a special "plow" on the front of a tug which forced the ice up and broke it by bending it in that direction. Neither system works too well when the ice is thick enough to hit bottom. A ship can turn around and back through it stern first and, providing it has twin screws, the propellers literally "eat" a channel through the jam. The plow variety tends to become a submarine, however, when the ice is grounded!

Break it as small as you can. For Ontario streams, a piece size of 1 - 2 m is desired.

8. LAST TO FREEZE IS FIRST TO OPEN

If you are looking for your first indication that spring is beginning to get to your ice, the places that froze over last are the ones to look at. They are the most likely places for break-up to begin as the cover is thinnest and the velocity is often high.

Anywhere the surface velocity is 1 m/sec or greater is a likely place for break-up to begin.

Figure 1. Rideau Falls emptying into the Ottawa River

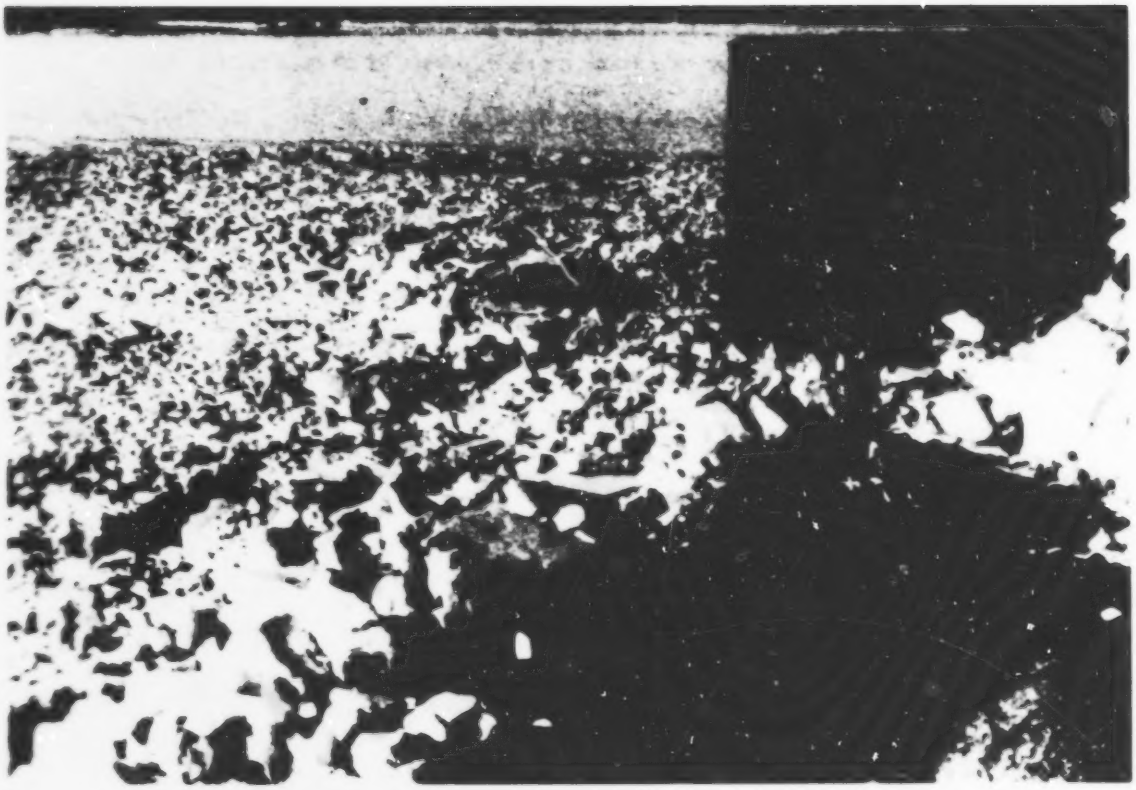


Figure 2. Looking downstream from Rideau Falls over the Ottawa River

9. THERE IS A CRITICAL FLOW CAUSING MAJOR BREAK-UPS

In this case, a general disintegration of the ice cover is being considered. The causes are:

(a) a rise of 1 m or more in levels in 24 hours; or

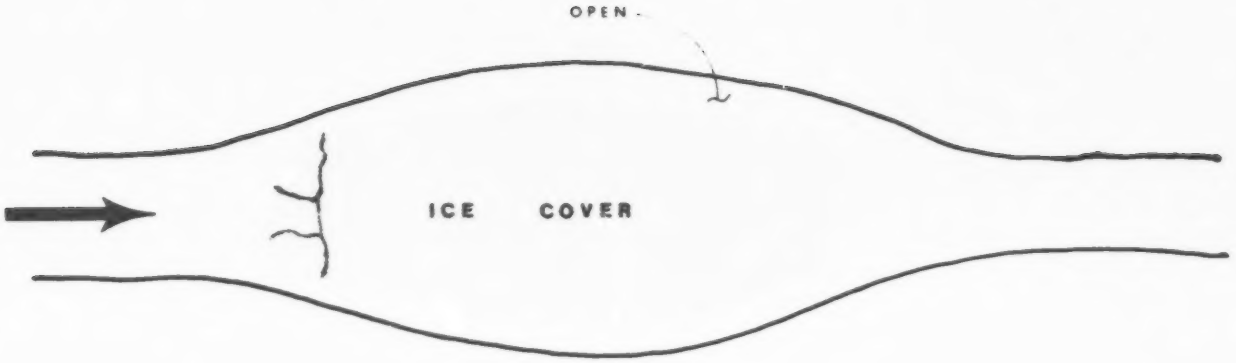
(b) a velocity of 1.5 m/sec or more.

If we consider the levels first, it is fairly clear that the narrow widths tend to cause the most rapid rises in levels, especially if the section is also shallow. When the flow increases to the extent that most of the ice cover is raised one metre or more, it tries to move downstream. As long as the main slab remains in one piece, it is restrained only by the odd island or by constrictions in width. If the downstream end moves into a velocity of 1 m/sec or greater, it will begin to break off the slab and there will be progressive break-up. If the downstream end is not in a high velocity area but the upstream end is exposed to a velocity of 1.5 m/sec or greater, the slab will begin to break from the upstream end, and again progressive break-up is likely. (See Figures 3a and 3b.)

As a preliminary indicator of this critical flow, one could expect that 60% of the 100-year flood would be enough to cause a major break-up if it occurs during the first week or two of mild weather. Variations between 50% and 70% of the 100-year flood may occur due to ice quality and weather sequences.

The worst combination for break-up is a sudden thaw extending over 4 days with rain. The resulting jams, however, will vary depending on how cold the winter has been, whether the ice is soft or hard, and whether it is thick or thin. In the final analysis, it is the sequence of weather events which is critical.

FIGURES 3 (a) and (b)



PLAN 3 (a)

SECTION 3 (b)

SOME NEW METHODS OF ICE DESTRUCTION

FOR THE CONTROL OF JAMS

by

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ABSTRACT

Preliminary ice destruction could be used to facilitate the break-up process. Powerful amphibians, equipped with ice splitters, can produce deep furrows with a speed of 15 km/hr. Two-fold increase of the efficiency of ice breakers and tow-boats was observed when they follow ice-splitter furrows. Solar deepening of these furrows divides ice cover into separate parts weakly connected with each other. These new methods of ice control could facilitate some typical problems.

Two main causes of ice jamming exist:

1. Local shortage of the drag power of a flood and its lack of ice destructive ability.

2. Local shortage of the transportation ability of the flood.

Two neighbouring sections of a river can be analyzed. One of them is situated in the relatively straight rectangular channel with depth h_1, width b_1, and velocity of water movement V_1. Another section with dimensions $h_2 = 2h_1$ and $b_2 = 2b_1$ is located in another part of the

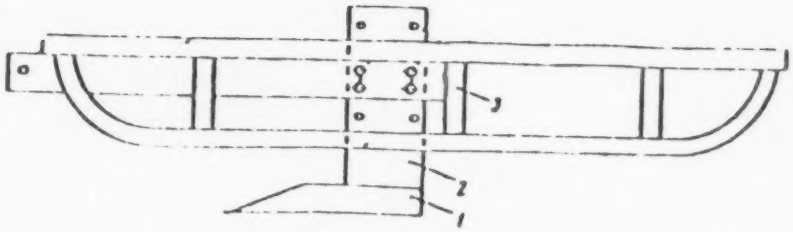
stream. According to the equation of continuity $V_2 = 0.25V_1$, the drag power could be taken proportional to the square of the velocity. Hence, the drag power in the second section is 1/16 of the drag power in the first section. Now, the transportation ability of flow in these sections can be assessed. It is proportional to the product width by velocity. Hence, the transportation ability in the second section is 1/2 of the first one.

It could be assumed that in the deeper and wider section, the shortage of drag power and of ice destructive ability of flood is much more probable than the shortage of ice transportation ability. Four main methods of ice destruction and weakening are well known; use of ice destructive machines, use of ice breakers, blasting and dusting. However, ice destructive machines are low in efficiency, ice breakers can work only in deep water channels, blasting is very expensive and dangerous for the environment, and dusting is expensive and not reliable. It is possible to say that we need a new approach to ice destructive technology to resolve ice problems on reservoirs. One of the possible new approaches is the use of ice splitters.

ICE SPLITTERS

An ice splitter is a very special ripper. Its cutter was designed on the basis of a large number of laboratory and field experiments to get the most effective ice destructive properties.
The ice splitter was designed as a separate unit. It is a strong iron sledge with one or more solid steel cutters which can be lowered or lifted and fixed in any one position (see Figure 1). A special cleaning wedge can be attached behind the ice splitter to remove debris from the furrow which is being produced.

To start furrowing, it is necessary to put the cutter on the surface of the ice. The cutter was designed for self-deepening and it can deepen when the ice splitter moves. The cross-section of the furrows is basically triangular, with the lower angle equal to 90 . However, the shape of the furrow depends on the depth of furrowing and on the ice conditions.



Specifications

Weight - 20 tonnes

Amphibian tractor capacity - 2 @ 240 = 480 hp

Volume of ice destroyed - 1500 m /hr.

Working speed - 15,000 m/hr

Typical size of debris particle - 50 mm

Fuel expenditure - 100 kg/hr

Figure 1. Ice Splitter: 1 - cutting blade; 2 - stem; 3 - sledge

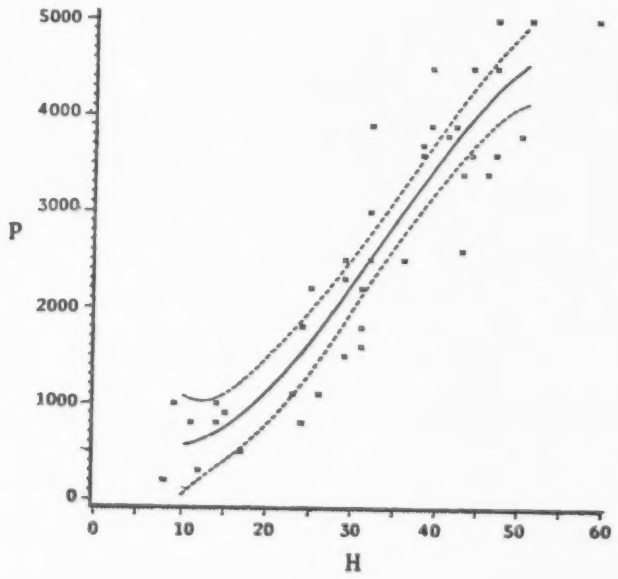


Figure 2. Tug power P, kg for ice splitter work versus depth of furrowing H, cm

The total tug power p for towing the ice splitter is equal to about 70 kg per 1 centimetre of the depth of H of the furrow when the furrows are shallow. For deep furrows, the tug power is about 80 kg per 1 centimetre of the depth. More exactly, the experimentally determined tug power could be approximated by the equation:

$$P = 984 - 105.7H + 7.08H - 0.071H \quad (1)$$

The results of the real tug power measurements and the approximation line with 95% confidence limits are shown on Figure 2.

Deviations from the approximation line are caused by variations of ice temperature and the depth of snow situated above the ice cover. When the snow is deeper than 60 cm, furrowing becomes very difficult. Powerful amphibians with a capacity of 240 hp were used for towing. Their tug power is 8 t nominally but, in practice on the river ice, this capacity is limited by low friction and by resistance of snow. Practically, it could be taken as only 5 t. It is enough to produce 35 cm deep furrows with a speed of 12-15 km/hr or the 45 cm deep furrows with a speed of 5-10 km/hr. However, it is better to work with the coupled amphibians. In this case, furrows with a depth of 65-70 cm could be produced, and the furrowing goes much more smoothly.

INCREASING THE ICE BREAKER'S EFFICIENCY

The ability of ice breakers to maintain continuous movement in ice cover mainly depends on their machines. Roughly, the thickness of ice cover H which an ice breaker can overcome continuously is proportional to the square root of the total capacity of its machines P, hp.

$$H = 0.0095P^{0.5} \quad (2)$$

It is necessary to use ice breakers with capacity of 5,000-6,000 hp to effectively destroy ice cover which is 0.7 m thick. However, the draught of large ice breakers restricts their use to channels, and only rarely permits their use in side parts of reservoirs. Because of that, it is

necessary to find a cheap, fast method to improve the efficiency of small ice breakers and to make possible their use in reservoirs instead of medium and large ice breakers.

The method of the ice breaker's work can explain the existence of the square proportionality between the power which is necessary to apply and the thickness of the ice cover being destroyed. Ice breakers destroy ice mainly by pressing the ice cover through, and the resistance of the ice cover is proportional to the square of its thickness.

When the ice breaker destroys the ice cover, it interacts with the ice by its stem and cheeks. It is a vexed question: which area of ice is the limiting one - the one which is opposite to the cheeks or that which is opposite the stem. Very often the ice in front of the cheeks is assumed to be the main area of the resistance of the ice cover (kashtelian et al, 1968, 1972). However, many years ago, M. K. Tarshis (1957) noticed that the power which is necessary to apply to break down the ice cover in the area of the cheeks is equal to 0.82σ and in the stem to 1.64σ. (σ is the limit of the flexural strength of ice. Thus, we can preliminarily assume the ice resistance in the stem area to be the main limiting resitance of the ice cover. We can also preliminarily assume that the ice resistance should be about half of normal if the ice cover in the narrow stem area only was half as strong as in the side areas. It means that a narrow furrow produced in front of the stem could double the speed of the ice breaker. The approximate depth of such a furrow Hf can be calculated:

$$Hf = H-(0.5H) \quad \text{or} \quad Hf = 0.3H \qquad (3)$$

According to this equation, the depth of furrows to double the ice breaker's speed in 40 cm ice is 12 cm, and in 100 cm ice 29 cm. However, even such a shallow furrow is often deeper than necessary. Actually, a furrow decreases the strength of ice cover greater than Equation (3) indicates. Possibly this is caused by a stress concentration produced by the furrow.

A number of experiments were carried out in order to ascertain the actual effect of ice furrowing and the minimum depth of furrows needed in order to obtain a radical increase of ice breaking speed. Four ships participated in these experiments, with power ratings varying from 500 hp to 22,000 hp. The speed of ice breaking was about doubled in the furrowed area. A special analysis shows that the increase of the ice breaking speed is almost independent of the depth of the furrows. It could be evidence that the stress concentration plays a much greater role than was assumed initially. However, it is possible that an area of weakened ice is located under the bottom of the furrows. This weakening could be caused by cracks which are directed from the furrow to the down surface of the ice. This weakened area could also be caused by melting. However, in all the experiments (without exception) a radical improvement of the ice breaking speed was revealed, even when furrows were very shallow.

RECORD OF DISCUSSIONS

The meeting was opened at 9:30 a.m. with registration and coffee.

At 9:45, John Ding, the Chairman, introduced Mr. Mike Garrett, Director of the Conservation Authorities and Water Management Branch. Mr. Garrett welcomed the participants to the Seminar and requested their input.

At 10:00, Derek Foulds gave an Overview of Ice Problems in Ontario. The following questions were asked:

Question — Is the ice boom in the Niagara River still in place?

Reply — (D. Foulds) - Yes, on a "test basis" it is put in each winter, beginning with the winter of 1965.

Comment — (L. Balogh) - There is a law suit being fought on this topic. The agricultural people feel that the boom sets the growing season back about 3 weeks.

Reply — (D. Foulds) - I have heard the reverse - that the farmers are pleased to have the boom in place, as it "prevents" too early a spring and subsequent frosts.

Question — (Dr. Tsykin) - Are jams in the spring always in front of the break-up?

Reply — (D. Foulds) - No. There is more than one kind of jam. The jams in the Niagara River often take place in January because of an early lake break-up. The majority of other break-ups are in the early spring, but you can get jams of frazil, broken ice, or sheet ice.

Question — (P. Crook) - Is the ice below Niagara Falls frazil ice?

Reply — (D. Foulds) - Yes and no. There are 30 km of open water upstream. By the time the ice gets to the falls, it could be 5 cm thick. Some of this, in the past, would have been pan ice from Lake Erie, and this is still possible today if the wind blows hard enough.

The next speaker, Dr. Tsykin, gave a detailed presentation on Ice Jams: Origin and Determination of Control Measures. Following this, there were more questions.

Question — (Forest Buckingham) - I would be interested in knowing the significance of temperatures after break-up.

Reply — (Dr. Tsykin) - The water flow is faster than the break-up movement. Hence, the break-up zone is being fed by water from already cleared parts of the river. The temperature of water greatly depends on weather in the just cleared parts of the river, i.e., on air temperature after break-up.

Thus, air temperature after the break-up indirectly describes water temperature in the break-up zone. Unfortunately, direct data on this parameter was not available for me. Use water temperatures if you can.

Question — (P. Gryniewski) - If someone has limited resources and wants to set up a monitoring system, what should the items be that he would measure, in priority?

Reply — (Dr. Tsykin) - All the parameters used in my calculations were calculated from the following observed phenomena:

1) Daily observation of stages;

2) Determination of daily discharges;

3) Ice thickness measurements;

4) Short descriptions of events, i.e., "ice cover", "movement of ice", "clear water", etc.

5) Weather observations.

This is a minimum. However, the observations should be organized in about 10 spots along an analyzed river.

Question (A. Chow) - Is the ice jam intensity coefficient an absolute value?

Reply (Dr. Tsykin) - I am not sure I understand the question. Are you asking how two rivers correlate between each other?

Comment I am referring to two different rivers where the coefficient with a larger value shows that river to be more susceptible to ice problems.

Reply (Dr. Tsykin) - It is an important question. To calculate variation, we should check a long section of the river to determine the size of the variation. The coefficient is based on a 24-hour backwater calculation on break-up day and may be used for comparison of ice jamming intensity of different rivers.

Question (A. Chow) - You used the figures 6.2 and 7.0. Does the larger figure mean there is more possibility of ice jamming?

Reply (Dr. Tsykin) - Yes, there is a different topography between the two rivers - one has steep slopes, and one is flat.

Question (J. Ding) - Does it mean the more irregular the river, the higher the coefficient of variation?

Reply (Dr. Tsykin) - Yes.

Question (D. Foulds) - How long a period of break-up does it take for the system to clear (days, weeks, months)?

Reply (Dr. Tsykin) - It depends what river you are talking about. Sometimes we have repeated movement of ice. Then, suddenly, one week later, there is more ice and it takes a couple of days to clear. Altogether, this process could take more than a week in some years.

Question (D. Strelchuk) - In your work, you completed a multiple regression analysis on the variables affecting ice jam break-up and then grouped the variables into four main groups. Two of these groups are power of flood and transport capability of the river. Could these variables be represented better physically by the Froude Number than by statistical analysis? Was the use of the Froude Number tested on the two rivers you investigated?

Reply (Dr. Tsykin) - I try to use the Froude Number for this purpose, but it is very often impossible to do because there are many subjective assumptions with the determination of this number, and these are very changeable. We usually do not know the Froude Number. If you have field observations which are sufficient to calculate the Froude Number, it is fine. Perhaps it could be used very efficiently for this purpose. Often the assumptions for this number are unrealistic.

Following a break for lunch, Paul Frigon discussed a Case Study: Monitoring Ice Jams on the Grand River. He was asked the following:

Question (P. Gryniewski) - Although you are not sure whether the blasting had any effect on the break-up of the jam, you must remember that the public relations effect is great.

Comment (C. Moore) - I could give you an example of a municipality that used the technique of placing explosives on the ice and ignited the charge. The ice jam broke and took out one of the most important bridges.

Question In terms of your blasting, how far downstream did you have open water?

Reply (P. Frigon) - There were 5 miles of ice below West Montrose. As we were discussing what to do, the flows were rising and things were happening. By the time we got to the ice jam, there may have been 1/2 mile of ice and 5 miles of open water.

Question (G. Montcalm) - Were you able to predict that there would be a jam because of the thickness of the ice?

Reply No. One thing we are attempting to do is measure the ice thickness at the same place at the same time each year. This should help us in estimating where jams will occur.

Question (Q. Alam) - Is there a relationship between the 2 sites on the same river?

Reply (P. Frigon) - No. The Grand Valley ice jam occurred this year, but nothing happened at West Montrose. Last year, the reverse happened. In the future, it may be possible to allow ice cover to form and avoid ice jams.

Question (Q. Alam) - Perhaps you could vary the flows to Shand Dam and prevent ice jams and flooding.

Reply (P. Frigon) - The problem is that if we kept the flows high, we would have flooded them anyway.

Question (Q. Alam) - How long do you keep the flow at 100 cfs for the Shand Dam?

Reply (P. Frigon) - You have to keep some flow in the river, and the minimum is set at 100 cfs. There were 28 degree days of flow before the West Montrose ice jam.

Question (O. Stirajs) - Was the reduction in flow responsible for the ice jam?

Reply (P. Frigon) - No, I don't think so. I am sure that the jam was due to the influx of ice from upstream. However, some of Derek Foulds' recommendations will be carefully studied.

Following these questions, Derek Foulds outlined the Principles of Ice Jam Prevention from Ontario Experiences. He was asked:

Question (D. Strelchuk) - If you have only 25% of the 100-year flow, will ice just melt without jamming?

Reply (D. Foulds) - Yes.

Question (O. Stirajs) - In 1976, the flow was approximately 80% of the 100-year flow, yet the ice never moved.

Reply (D. Foulds) - There are year to year variations in the quality of ice, and this will disprove most theories. The rate of rise in level due to the flow increase may have been the key. In Ontario, we design works to the 100-year flood, and tend to ignore the winter flow.

Question (R. Chang) - How do you form an ice cover?

Reply (D. Foulds) - I believe you are referring to those rivers with no flow control. If you know the number of areas that give you problems and you can induce the formation of cover through ice booms, you can form ice cover very quickly. If an ice boom gets overloaded, it will duck. The only other way is to pray and wait.

Question (Q. Alam) - We changed the outlet flow to make sure that there was some bottom erosion. Will this help in preventing ice jams?

Reply (D. Foulds) - Yes, because the water will be slightly warmer. Also, alluvial beds are very prone to problems. If you have a good jam, this will clean out the bottom again. I do not know if a jam is always a bad thing - only if people live in the area.

Question (D. Strelchuk) - Are ice break-up conditions you discuss generally for normal spring break-up only? In some cases like the Moira River, flooding can occur in February due to ice jamming caused by a sudden thaw accompanied by rainfall. Under these conditions, flows much less than 50% of flood flows have caused flood damages.

Reply (D. Foulds) - What made the ice move? - could you do anything to prevent that cover from moving by using controls? Could you control the movement by an ice boom? If you keep the ice out of critical areas, control is less of a problem. Also, some rivers have nasty habits of their own and some theories will not work. Also, in some cases, development in flood plains results in flood damages occurring under less severe criteria.

Question (O. Stirajs) - The islands that you mention - are they artificial?

Reply (D. Foulds) - Yes.

Question (O. Stirajs) - Are they there all year round or are they just placed in the fall?

Reply (D. Foulds) - Most of them stay in all year round. If you put an island in, you cut down on the size of the cross-section, and maybe increase the velocity so that they may be self-defeating.

Question (O. Stirajs) - What are the islands made of?

Reply (D. Foulds) - They are usually dirt with armoured protection - usually classified rock.

Question (G. Montcalm) - Does the head have a great effect on breaking a jam?

Reply (D. Foulds) - Yes. It produces high velocities and pressure which tends to push the ice jam up. Once it gets up, the stream will spill over the banks.

The final speaker of the day was Dr. Tsykin who discussed Methods of Ice Jam Control: Solar Ice Melting, Mechanical Ice Destruction and the use of Ice Breakers. The following questions were asked:

Question (J. Wang) - What is the rate of melting, if you assumed that all of the radiation is absorbed by the ice?

Reply (Dr. Tsykin) - Experiments in Arkhangelsk were carried out when the average radiation rate was 250 cal/cm^2/day. It corresponds to the rate of melting of about 3 cm/day when albedo is conditionally assumed to be 0% and air temperature = 0° C. In real conditions, when albedo was about 30% and air temperature often below 0o C, the rate of melting on the surface was much less that 0.5 cm/day, and mostly zero.

Question (D. Foulds) - You refer to grams of dust melting ice to become so many grams of water - have you tried to express this in terms of thickness?

Reply (Dr. Tsykin) - Everything depends on the intensity of solar radiation, with about 1 - 3 cm melting per day. This means 1 - 2 weeks of acceleration in melting after the snow has gone.

Question (Q. Alam) - What material do you use for dusting?

Reply (Dr. Tsykin) - We use different materials - black or dark gray - sand, coal and slag. The best is slag. If we use aircraft for distribution of the dust, it is cheaper to prepare good dust and use less than to use unsorted slag and use more. However, if aircraft is not used and the dust is distributed by street vehicles (just as salt is scattered on the snow on roads), it is too expensive to use sorted dust particles.

Question (N. Paroschy) - Are there any environmental problems with dusting the ice?

Reply (Dr. Tsykin) - This depends on how strict the environmental rules are in any part of the country. Sometimes we get resistance from environmental departments who tell us that fish can be destroyed by introducing artificial material into the river.

Question (R. Chang) - Have you done any experiments on patterns of dusting, or do you just dust at random?

Reply (Dr. Tsykin) - This is a very important question. It is very difficult to distribute the dust evenly. There are always many particles that overlap after dusting. When we use aircraft, the planes have good quality distribution mechanisms and we have no problems. It is so quickly distributed that it is a pleasure to see. If we use road vehicles, sometimes there are problems and we get results well below those demonstrated.

Question (Bill Newell) - How much snow over dust will render it useless?

Reply (Dr. Tsykin) - It depends on the rate of dusting. For a rate of 25 g/m^2, only 2 cm of snow is enough to make dusting useless. However, a snow cover of 5 - 7 cm still does not stop some additional melting when 500 g/m^2 rates of dusting were applied. Both given examples are working when are temperatures are assumed at about 0^o C.

Question (G. Montcalm) - When is dusting started in the winter?

Reply (D. Foulds) - It is at your own risk. Dusting too soon means that the snow will get covered before it can work, and dusting too late will be ineffective.

Question (L. Balogh) - Was there any difference between the efficiency of ice furrowing and the depth of the water under the ice surface?

Reply (Dr. Tsykin) - The problem was not studied. However, the mechanisms of furrowing and of self-deepening of furrows has no connection with the depth of rivers. The influence of furrows on the break-up process depends on the kinds of stresses on the ice cover during the break-up. Furrows can not help when there are mainly compression stresses (ice transportation difficulties). Furrows are helpful when many shearing stresses exist in ice cover (ice destruction difficulties).

Question (P. Crook) - Does the ice have to soften a little before the use of an ice splitter?

Reply (Dr. Tsykin) - Generally, no. There is a relationship between furrowing and tug power necessary to pull the device.

Question (O. Stirajs) - Do furrows created by the ice splitter refreeze completely?

Reply (Dr. Tsykin) - In my practice, they never refreeze completely. There is always some water under the ice cover in the furrows.

Question (A. Chow) - The furrows affect the efficiency of ice breaking. Is this a fuel efficiency or a time efficiency?

Reply (Dr. Tsykin) - It is a time efficiency, calculated by fuel expenditure per hour, i.e., the amount of joules spent by any mechanism in 1 hour was divided by the amount of ice destructed during the same time. The result is the energy expenditure per cubic metre of ice destructed by each ice cutting machine.

Following the questions, John Ding thanked the speakers for their efforts and thanked the participants for coming and sharing their problems. The meeting was adjourned at 4:30 p.m.

LIST OF PARTICIPANTS

Quazi Alam	MNR, Central Region
Lew Balogh	MNR, CAWM Branch
Bob Beecher	MNR, Eastern Region
Al Bonnis	Nickel District C.A.
Mike Brewes	Credit Valley C.A.
Prof. Forest M. Buckingham	University of Toronto
Andy Burt	Mississippi Valley C.A.
Ian Cameron	MNR, CAWM Branch
Bill Campbell	Central Lake Ontario C.A.
Clark Campbell	MNR, Southwestern Region
Robert Chang	MNR, CAWM Branch
Len Chapman	MNR, CAWM Branch
Allan Chow	MNR, North Central Region
Wayne Corry	MNR, Algonquin Region
Peter Crook	MNR, Southwestern Region
John Ding	MNR, CAWM Branch
Derek Foulds	Uxbridge, Ontario
Rob Fox	MNR, CAWM Branch
Paul Frigon	Grand River C.A.
Mike Garrett	MNR, CAWM Branch
Peter Gryniewski	MNR, CAWM Branch
Don Haley	Metropolitan Toronto and Region C.A.
Jeff Hueston	MNR, Northern Region
Jeff Jelik	MNR, Southwestern Region
John Johnston	Moira River C.A.
Ilmar Kao	Grand River C.A.
Ken Keyes	MNR, CAWM Branch
Christine Kowalyk	MNR, CAWM Branch
Leo Kwan	South Lake Simcoe C.A.
Bill McMullen	MNR, Algonquin Region
Greg Montcalm	South Nation River C.A.
Carey Moore	Halton Region C.A.
Ron Moulton	Grand River C.A.
Wes Mount	Lower Trent Region C.A.
Dennis Murray	MNR, Eastern Region
Bill Newell	Ganaraska Region C.A.
Nick Paroschy	MNR, Northeastern Region
Werner Plessl	Hamilton Region C.A.
Guirish Sardesai	MNR, CAWM Branch
Emil Stasyshyn	Atmospheric Environment Service (AES)
Olie Stirajs	Rideau Valley C.A.
Rolly Stork	MNR, Eastern Region
Dave Strelchuk	MNR, CAWM Branch
Eugene Tsykin	Alcoa of Australia Ltd.
Heda Whitson	MNR, CAWM Branch
John Wong	Environment Canada, Burlington

Abbreviations:

MNR - Ministry of Natural Resources
CAWM - Conservation Authorities and Water Management
C.A. - Conservation Authority